NOAA Forecast Systems Laboratory
2002 Technical Review

GPS-Met Observing Systems

Presented by

GPS-Met Observing Systems Branch
NOAA Forecast Systems Laboratory Demonstration Division

May 14, 2002

GPS-Met Observing Systems

- ***Overview/Introduction:*** (1330 - 1350) — *Seth Gutman*
- ***Data Acquisition, Processing & Dissemination:*** (1350 - 1430) — *Mike Foy, Kirk Holub, Susan Sahm, Jebb Stewart*
- ***Break:*** (1430 - 1445)
- ***Selected Projects:*** (1445 - 1515) — *T. Smith, S. Benjamin, & B. Schwartz*
  S. Solomon & B. Sierk
  S. Gutman
- ***Future Directions:*** (1515 - 1525) — *Seth Gutman*
- ***Questions:*** (1525 - 1530)

Overview/Introduction

- The GPS-Met project started as a collaboration between FSL and universities to determine if-and-how GPS could be used to measure atmospheric moisture.
- It has evolved into a collaboration between FSL, other NOAA organizations, other federal, state and local government agencies, universities, and the private sector.
- This level of cooperation has permitted us to develop and evaluate a new upper-air observing system for NOAA in about 7 years, for less than 10% of the Demonstration Division’s budget.
- We have participated in the development of real-time data processing techniques, demonstrated that these data have a positive impact on Wx forecast accuracy, and explored new observing system paradigms.

Tech/Scientific Collaborations

FSL	AD, FRD, ID, SDD, Directors Office
NOAA Research	ETL, AL, AMOL, PMEL, GLERL
Other NOAA:	NWS (NDBC, ER, SR, CR, WR, AR, NCEP), NOS (NGS, CO-OPS), NESDIS (ORA)
Federal Gov’t:	DOT (USCG, FHWA), DOD (USN, USAF, USACE), NASA (LaRC, JPL, IGS), DOE (ARM)
Universities:	SIO, UH, UNAVCO, MIT (GAMIT, LL,), H-SAO, Purdue, PSC
Other Gov’t:	FDOT, MDOT, OkDOT, MCCO, OhDOT, TxDOT

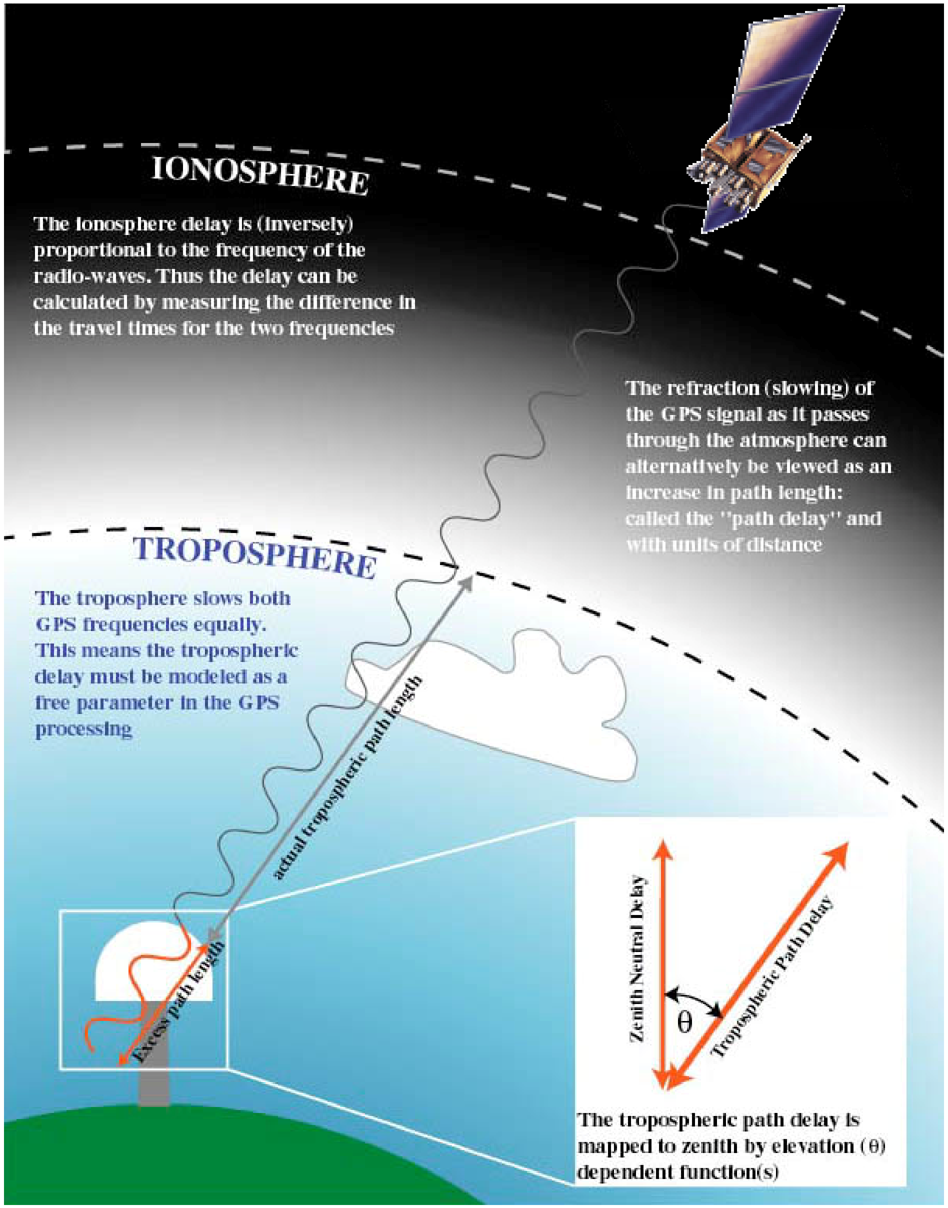
“If we have been able to see further, it is only because we have stood on the shoulders of giants.” (paraphrased from Isaac Newton’s Letter to Robert Hooke)

GPS-IPW Measurements

- Water vapor variability is largely responsible for time-dependant errors in GPS positioning, especially in the measurement of elevation.
- To mitigate this problem, Geodesists developed techniques to treat the signal delays caused by the neutral atmosphere as a nuisance parameter and remove them to improve survey accuracy.
- Verification of the accuracy of these signal delay estimation techniques led to the development of a new atmospheric remote sensing tool called ground-based GPS-Met.
- In ground-based GPS-Met, we use data from a network of GPS sites, in conjunction with improved GPS satellite orbits, to estimate the ***total excess signal path length*** caused by the refractivity of the atmosphere.

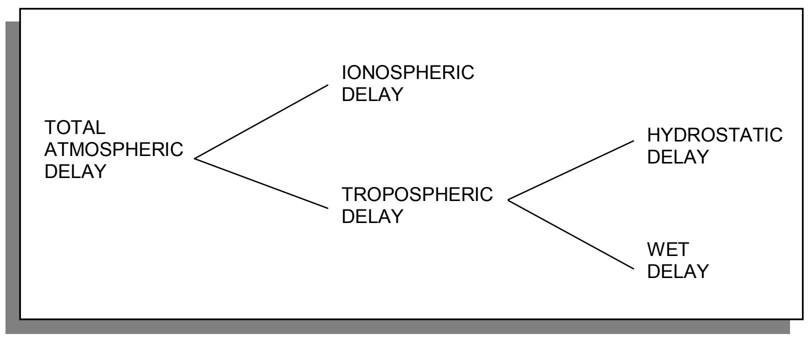
GPS-IPW Measurements

Forecast Systems Laboratory
Boulder, Colorado

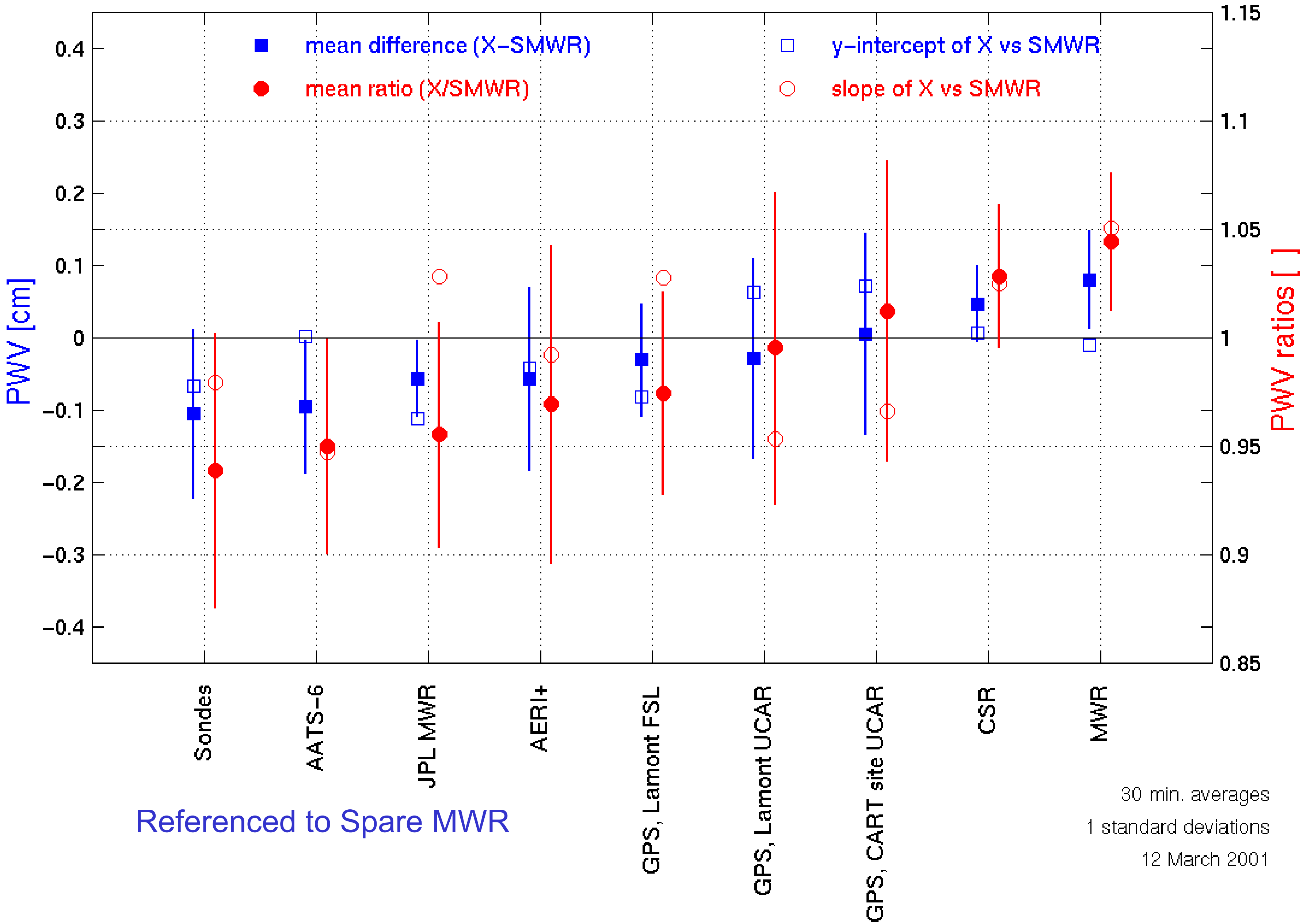


- Signal delays caused by the neutral atmosphere have a wet and dry component.
- The dry delay is caused by the mass of the atmosphere, and can be estimated with high accuracy from a surface pressure measurement.
- The wet delay is simply the difference between the total delay and the dry delay.
- The ratio of the wet delay to the dry delay is the integrated mixing ratio.
- The wet signal delay is nearly proportional to the total quantity of precipitable water vapor in the atmosphere directly above the GPS site.

GPS Signal Delay Structure



ARM WVIOP 2000 IPW
Data Comparisons (Clear Sky)



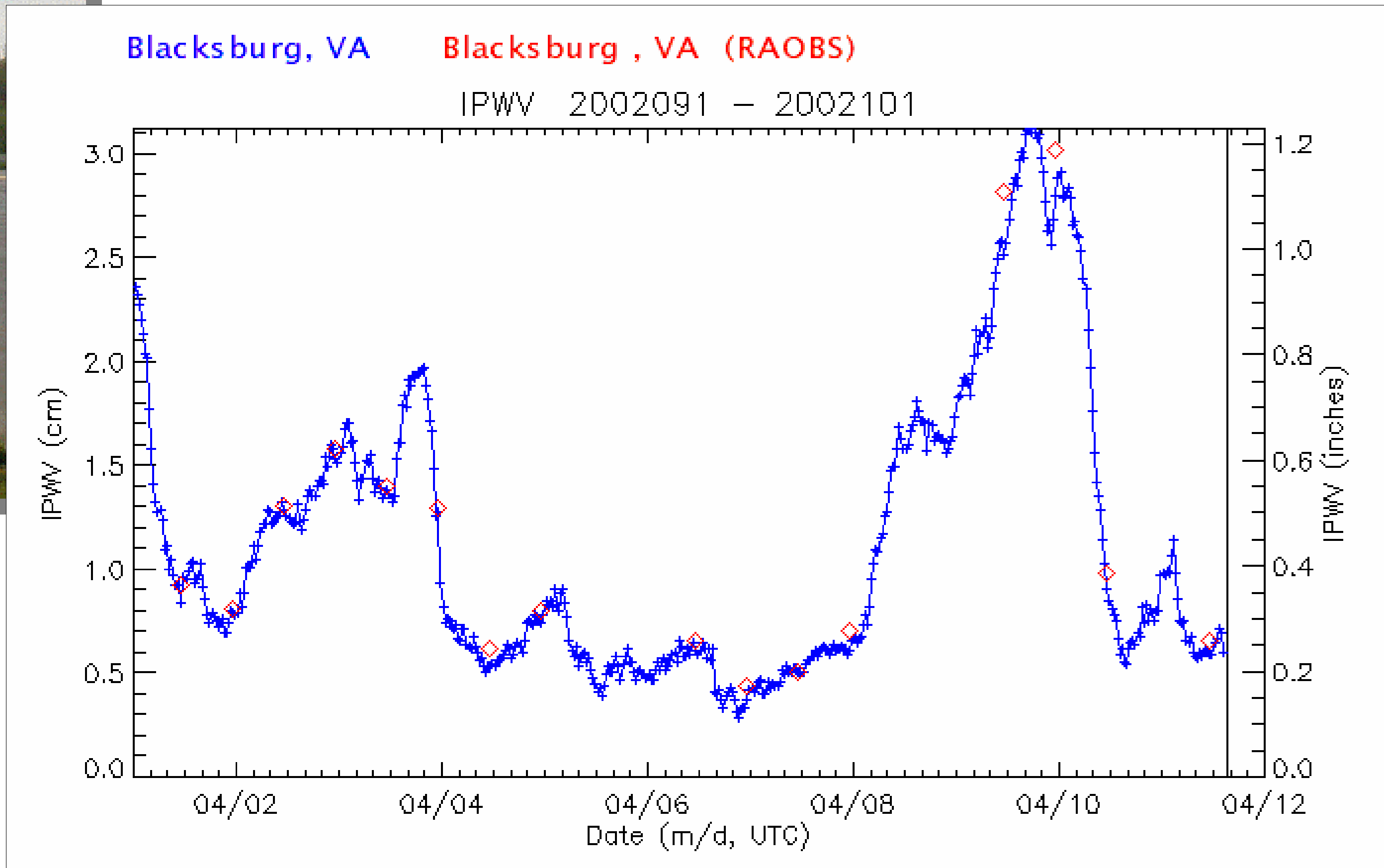
Referenced to Spare MWR

GPS-IPW Measurements

The Use of GPS Integrated Precipitable Water Measurements To Supplement WSR-88D Parameters in Determining the Potential for Flash Flood Producing Rainfall.

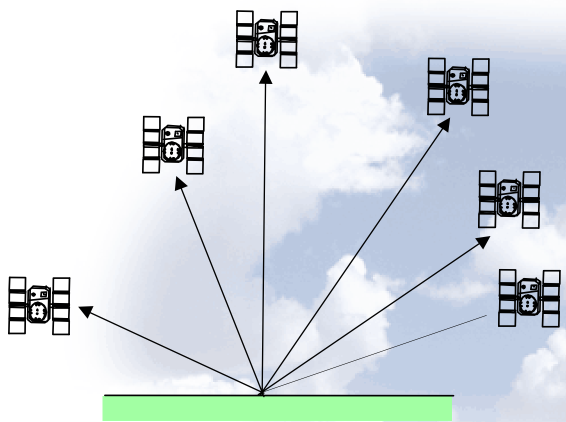
A UCAR/COMET Partner Grant Project by:

Stephen J. Keighton and Michael Gillen (NOAA/NWS Blacksburg, VA), and G.V. Loganathan, Srikanth Gorugantula, and Troy Eisenberger (Virginia Polytechnic Institute and State University, Blacksburg, VA)



Slant-Path GPS Measurements

Forecast Systems Laboratory
Boulder, Colorado



$$N = \boxed{-40.3x10^{6}\frac{:_e}{f^2}} + \boxed{77.6\frac{P_d}{T}} + \boxed{70.4\frac{P_v}{T} + 3.739x10^{5}\frac{P_v}{T^2}}$$

$$\underbrace{\quad\quad}_{\text{Ionospheric Term}} \quad \underbrace{\quad\quad}_{\text{Dry Term}} \quad \underbrace{\quad\quad}_{\text{Wet Term}}$$

N = refractivity = (n-1) x 10^6

$:_e$ = electron number density (m^{-3})

f = radio frequency (Hz)

P_d = atmospheric pressure (hPa)

P_v = water vapor pressure (hPa)

Fundamental Measurement

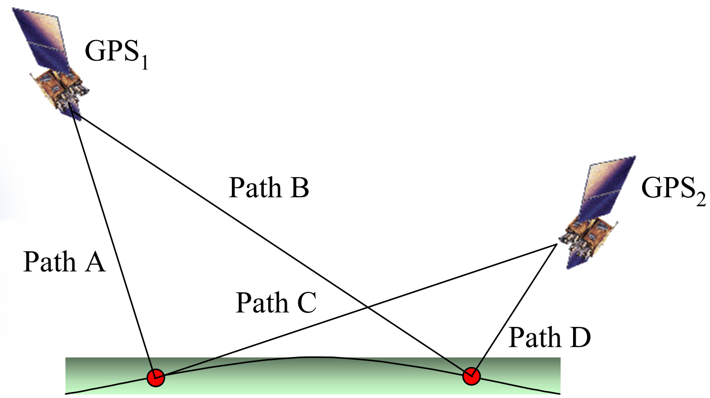
$$L_s = \int n(s)ds$$

- "Slant-Path" GPS is defined as an estimate of the excess signal delay (or apparent increased signal path length) caused by changes in refractivity along the path between a single GPS receiver on the ground and a single GPS satellite in space.
- A.E. "Sandy" MacDonald showed that it should be possible to retrieve the vertical distribution of water vapor in the atmosphere from slant-path delays (***SPD***) measured by a network of 'closely spaced' GPS receivers using a 3-dimensional variational analysis technique developed by Yuanfu Xie (MacDonald and Xie, 2001) .

Slant-Path GPS Measurements

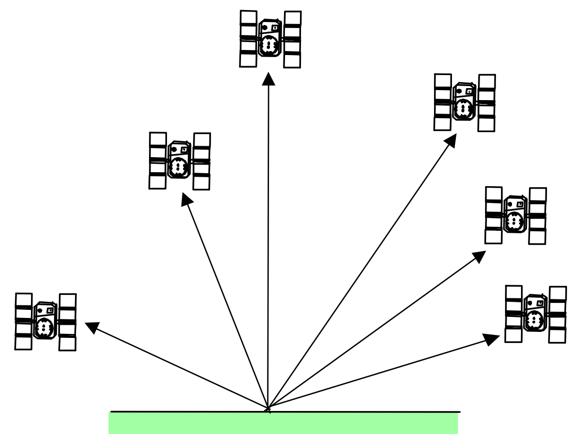
- When we process GPS data, we first form an "ionospheric free" carrier phase solution by combining L1 & L2, and then form a "double-difference" (DD) to remove receiver and satellite clock biases.
- We start with the assumption that the properties of the neutral atmosphere vary only with elevation, and that the total neutral signal delay has only a wet and dry component.
- The GPS signal delay along a single slant path, T("), is modeled in terms of an unknown "zenith delay" and known elevation angle-dependent mapping functions, m_W(") and m_D(").
- Since there are usually 6-10 satellites at different elevations in view at all times, solutions for the zenith delay (and its spatial gradients) are ***over-determined*** and can be estimated with high accuracy.

$$M_{IF} \cong 2.546\ M_{L1} - 1.984\ M_{L2}$$



DD = (Path A - Path B) - (Path C - Path D)

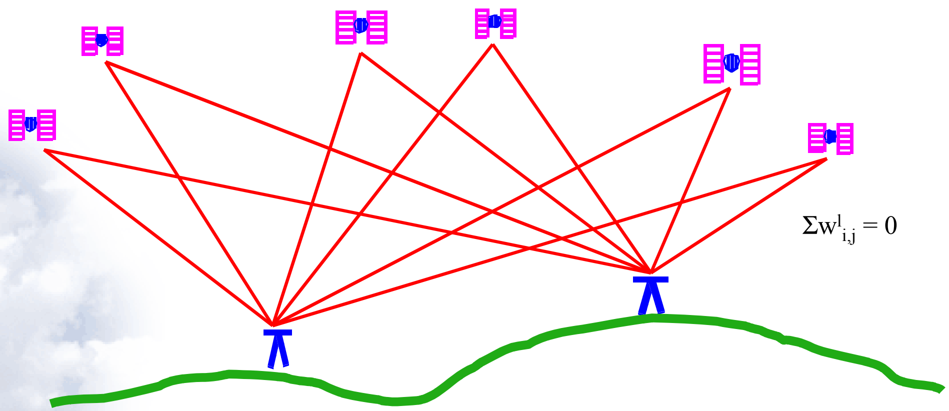
$$T(\alpha) = m_D(\alpha) * Z_D + m_W(\alpha) * Z_W$$



Slant-Path GPS Measurements

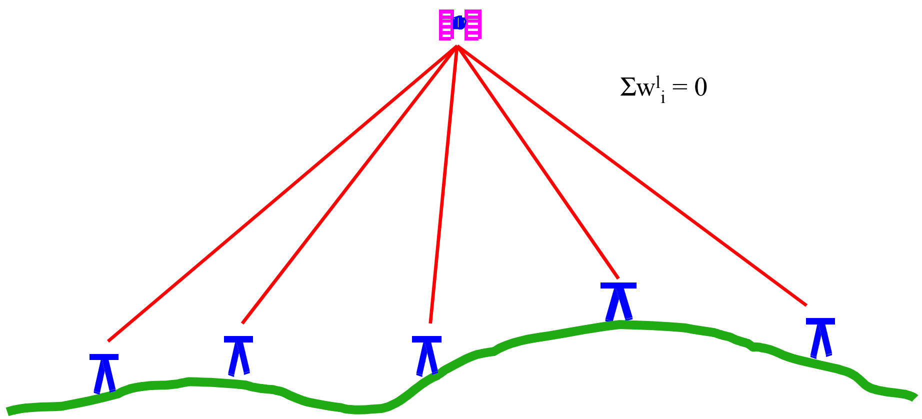
- With only one satellite and one receiver, the value of zenith delay is fundamentally underdetermined.
- This means that neither the zenith delay nor the SPD can determined ***uniquely*** from the basic GPS observation because of simultaneously unresolvable receiver and satellite clocks biases, uncertainties in site & satellite positions, and multipath.
- Because of this, all SPD solutions are ***very sensitive*** to the initial conditions, assumptions, and constraints used to estimate the wet and dry delays along the slant path.
- The most commonly used method to do this is to compute a zero difference from a double differenced observation by inverting or 'un-differencing,' and assuming all differences have a zero mean.

Inversion From Double to Single Differences



- All double differences within a baseline are used in this step.
- Station Errors (PW biases, coordinates, etc) must be accurately modeled
- Any error in "zero" assumption is distributed to all single differences within the baseline.

Inversion From Single to Zero Differences



- All single differences to an individual satellite are used in this step.
- Any atmospheric delay observed by all stations in this step is not detectable.
- Any error in this assumption is distributed to all stations in the network.
- The more stations the better, the larger the network size the better.

Slant-Path GPS Measurements

- Notwithstanding these difficulties, it may still be possible to make a true slant-path delay measurement using GPS, and ***the payoff is potentially enormous***.
- How to do this requires a complete reevaluation of how GPS observations are made, and how we model or constrain the errors and uncertainties inherently associated with it.
- In addition, ***methods to verify the measurement*** need to be developed and validated.
- Pedro Elosegui and Jim West from the Harvard-Smithsonian Center for Astrophysics have just been awarded a small grant from FSL to study the problem from first principles.
- Results are expected within one year.

Supporting the FSL Strategic Plan

- FSL conducts applied meteorological R&D to create and improve short-term warning and weather forecast systems, models, and observing technology.
- Ground-based GPS-Met addresses one of the deficiencies in NOAA's upper-air observing system by providing high accuracy moisture observations under all weather conditions.
- The unique capabilities of FSL have enabled the GPS-IPW observing system to be developed, tested, and validated end-to-end in a relatively short period.
- Positive impact on Wx forecast accuracy has been demonstrated and verified using the FSL-developed RUC.
- The FX-Net workstation has allowed us to prototype GPS-Met data visualization techniques and evaluate products for forecasters.

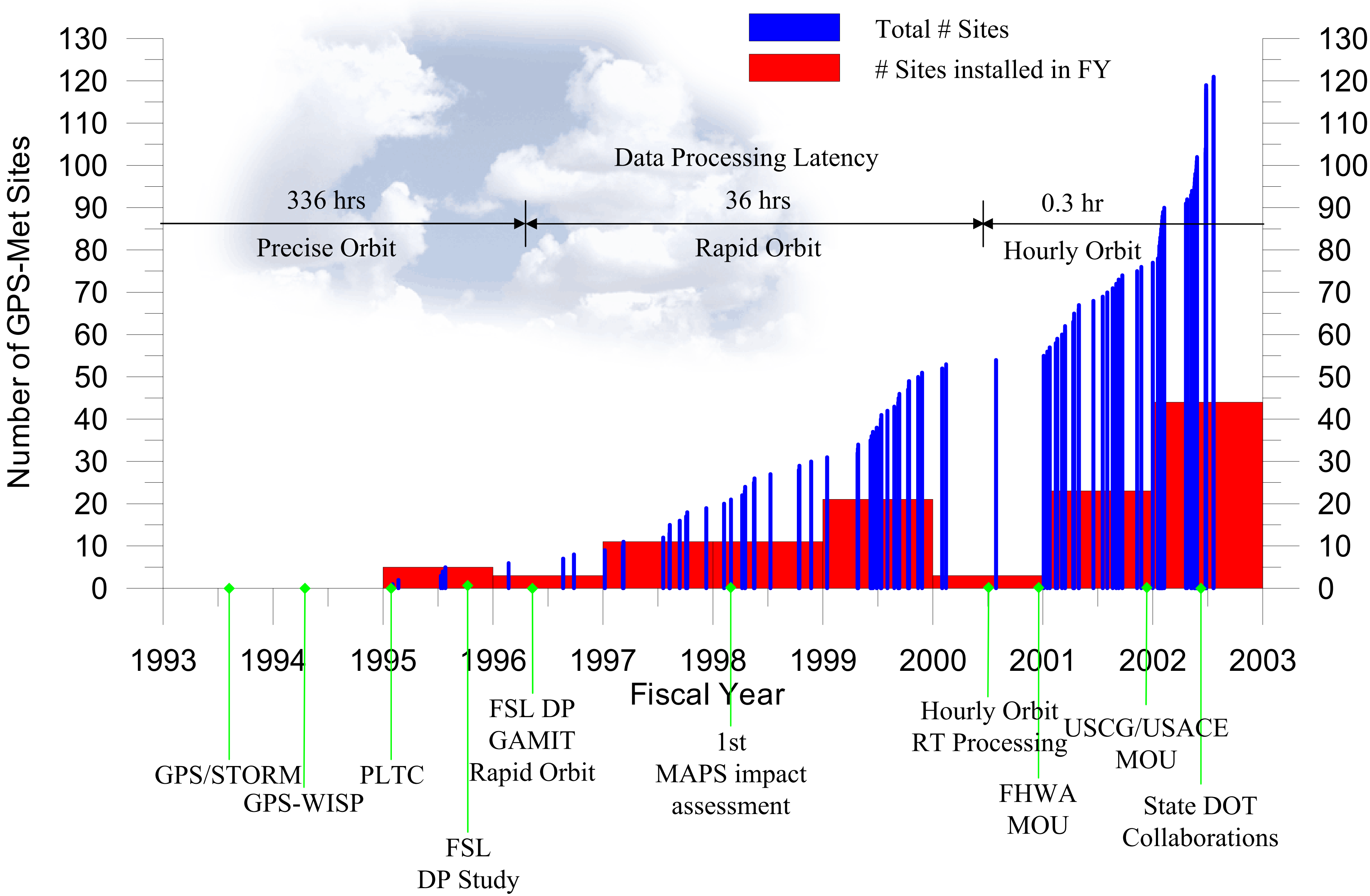
Technology Transfer/Outreach

- FSL transfers new scientific and technological advances to its clients, including the National Weather Service, Department of Defense, foreign weather forecasting agencies, and private interests.
- To facilitate this, DD is funding a modest outreach activity led by Sher Wagoner of FSL/AD and CIRA. Initial results include:
  - The 45WS at CCAFS is experimenting with a lightning prediction index that utilizes GPS-IPW data. The index was developed with assistance provided by FSL. We expect expanded collaboration with FSL on the use of GPS-Met data at CCAFS and NASA KSC;
  - AFSC at Shriever AFB is evaluating the use of GSOS met sensors and FSL GPS-Met data processing techniques at USAF GPS tracking and control stations to improve GPS data & product quality.

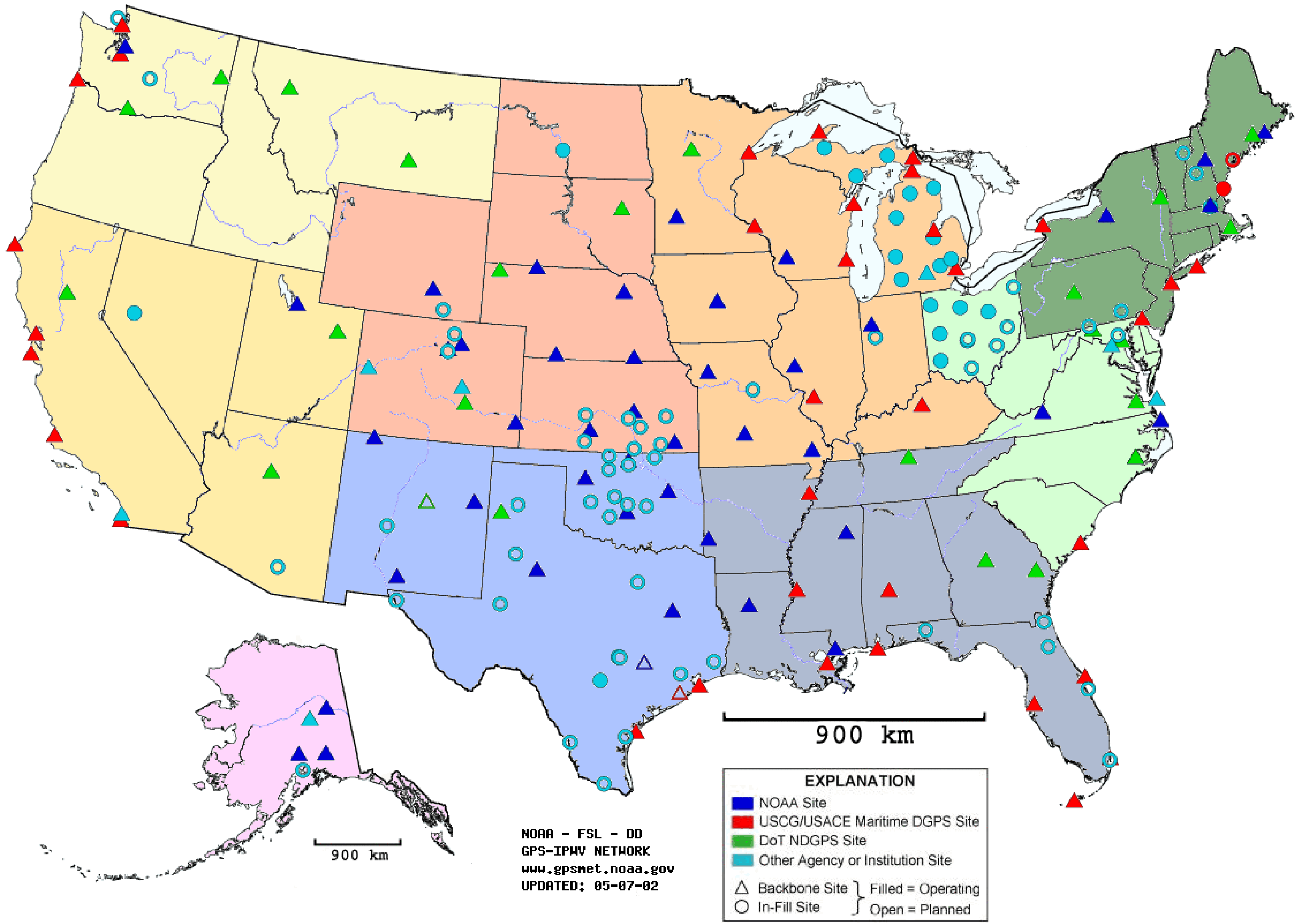
Technology Transfer/Outreach

- Initial discussions between FSL, SEC, and USAF on the formation of a joint data processing center for the operational use of GPS radio-occultation (RO) data. The RO data will come from a proposed constellation of USAF BMD satellites in LEO. In addition to the primary military use of these observations, RO data may have significant utility for NOAA global climate monitoring.
- Installation of a GPS-Met system at the Salt Lake City WFO to support the Winter Olympics and ongoing moist season precipitation forecasting on the western slope.
- Educating NWS and DoD operational weather forecasters on the availability and use of GPS-Met data. Presentations to Eastern, Central & Western Region SOO's.
- Ongoing effort with DOT FHWA to expand awareness and gain support for the N/DGPS program.

History, Evolution & Critical Decisions



GPS-Met Demonstration Network



121 GPS-Met Sites + 52 waiting for positions

NOAA Forecast Systems Laboratory
2002 Technical Review

Data Acquisition, Processing, and Dissemination

Kirk Holub, Jebb Stewart & Mike Foy
Systems Research Group, Inc.

Susan Sahm
NOAA Forecast Systems Laboratory

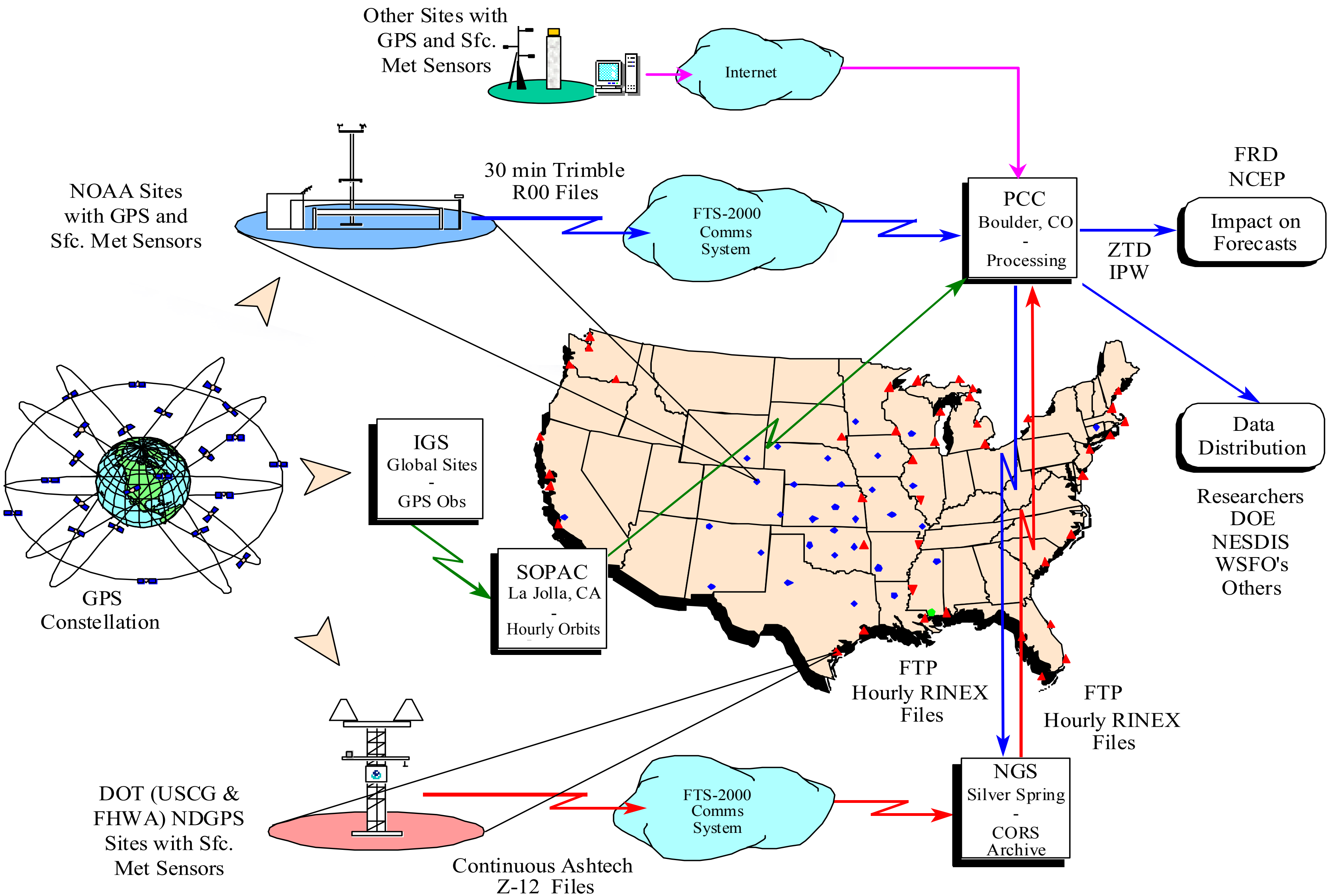
May 14, 2002

Outline

- Data flow
- Network Implementation
  - Data acquisition
  - IPW processing
  - Data dissemination
  - Processing geometry
- Major implementation changes since April 2000
- Web-based displays
- Plans and problem mitigation strategies

- Next-step Directions
  - Surface pressure at in-fill sites
  - Improving GPS-IPW retrievals

GPS-Met Data Flow



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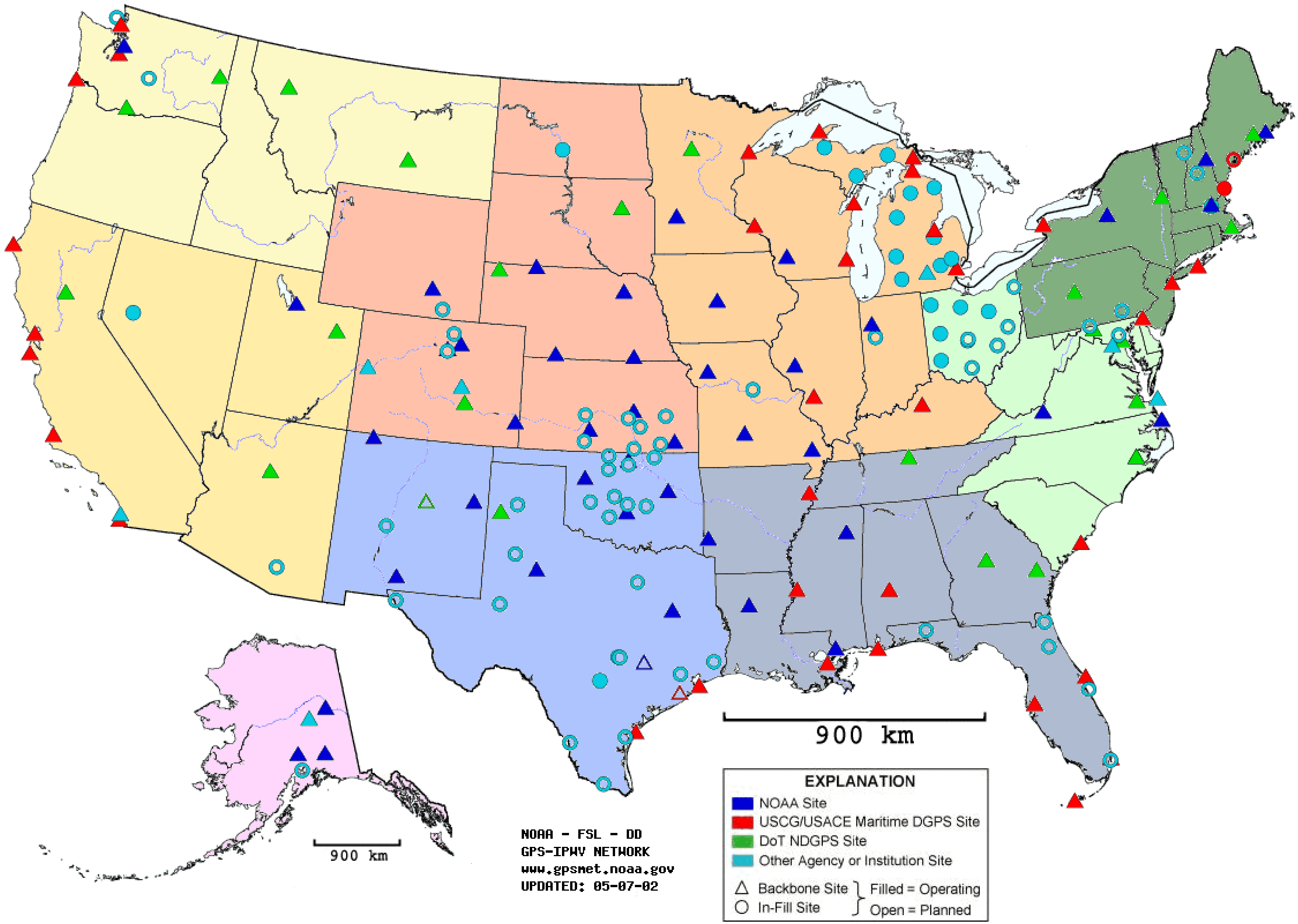
GPS-Met Demonstration Network

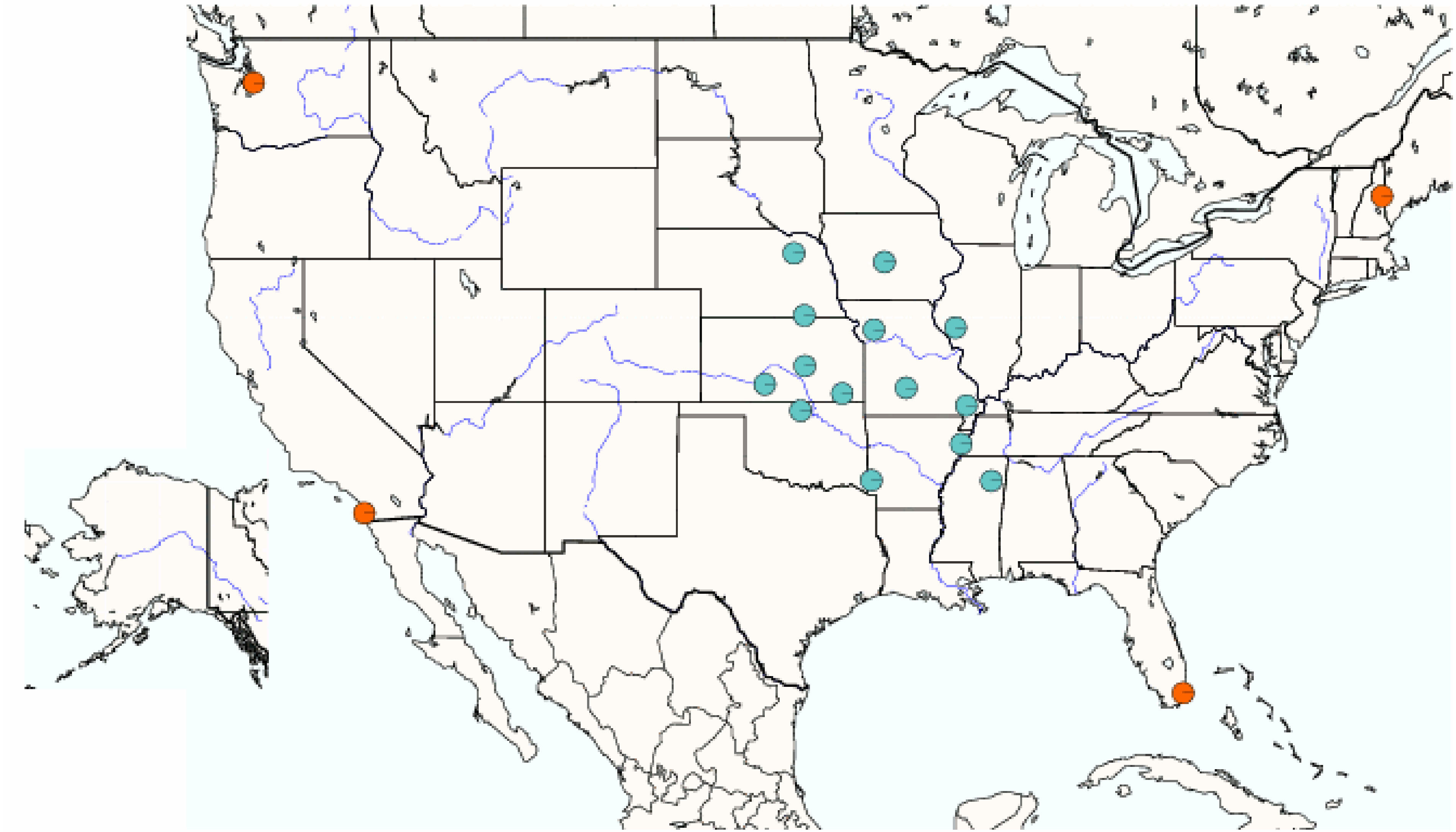


121 GPS-Met Sites + 52 waiting for positions

Network Implementation

- The GPS-Met Demonstration Network consists of two types of sites, *Backbone* and *In-fill:*
  - ***Backbone sites*** belong to NOAA or other federal, state and local government agencies. They have collocated surface met sensors and are maintained as operational systems and as such are considered to be trusted public resources.
  - ***In-fill sites*** belong to government agencies, universities, or other organizations for educational, research, or proprietary applications. They are not necessarily maintained as operational systems and the owners are not obligated to do so.
- The network will expand by acquiring data from both types of sites. In the near term, most will be backbone sites belonging to agencies like NOAA, FHWA and USCG.

Data Processing Geometry



Data Processing Geometry

- Data processing is performed using small groups (12 to 16) of sites, referred to as sub-networks
- In addition to its actual sites each sub-network contains four fiducial sites
- During processing the positions of the fiducial sites are tightly constrained while the positions of the other sub-network sites are more loosely constrained
- This geometry exploits the observation that IPW measure at two closely spaced sites is highly correlated and IPW measured at two widely spaced sites is highly uncorrelated

Data Acquisition

- Data are acquired from 4 types of sites
  - NPN and Other NOAA sites (ONS) (FSL has direct responsibility for GPS & MET payloads)
  - OAS (Other Agency Sites)
  - SOPAC (GPS orbits and EOP)
- Quality control is applied, formats are changed, and names are made compatible
  - Primarily applied to NPN and ONS sites
- System contains multiple possible single points of failure
  - Availability of high precision orbit data
  - A single host serves 'raw data' using NFS (Network File System)
  - A single host serves as the 'focal point' for all IPW estimates
  - However, its performance is generally good as demonstrated by http://gpsmet.noaa.gov/displays/rt_gmp_current.html

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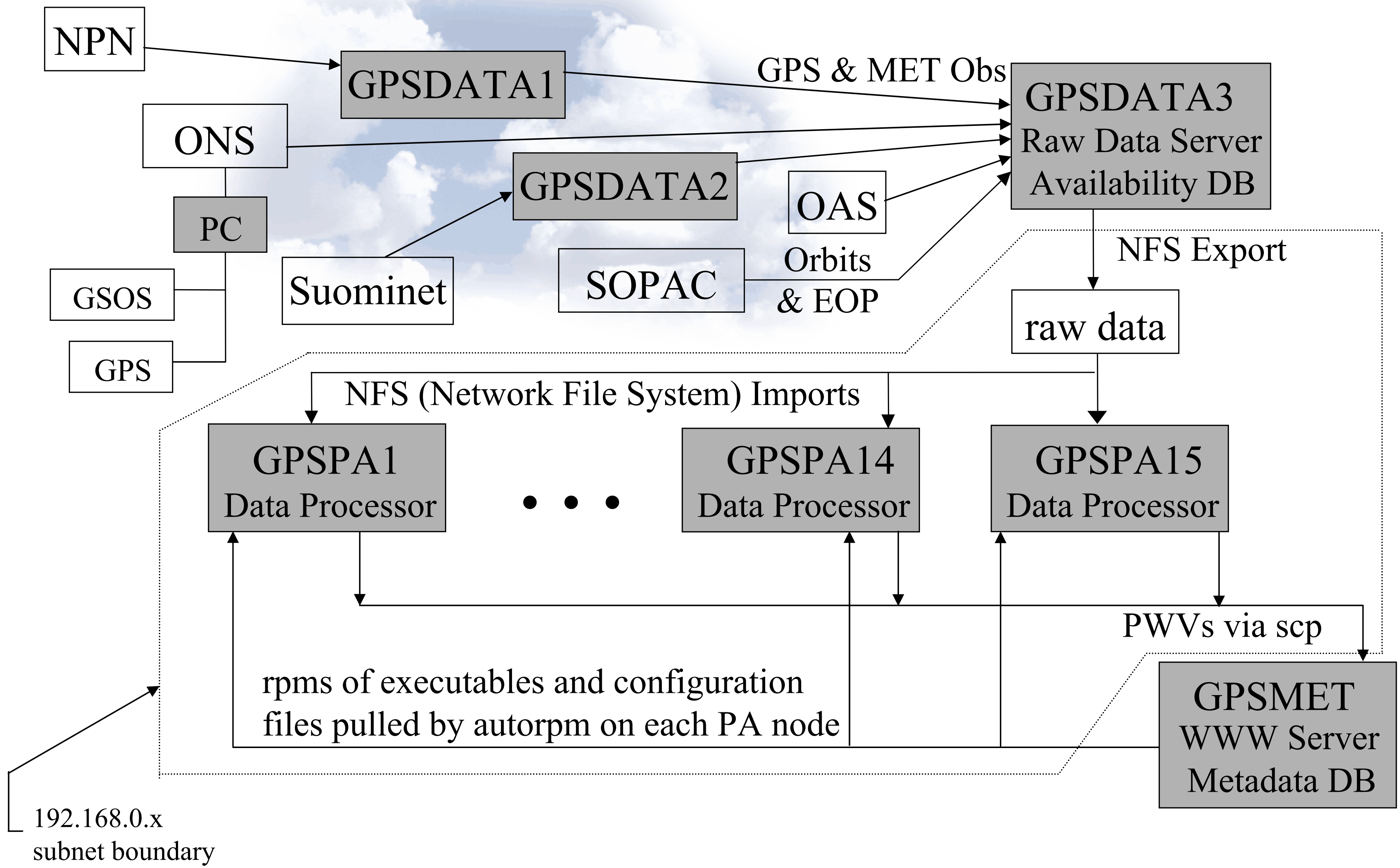
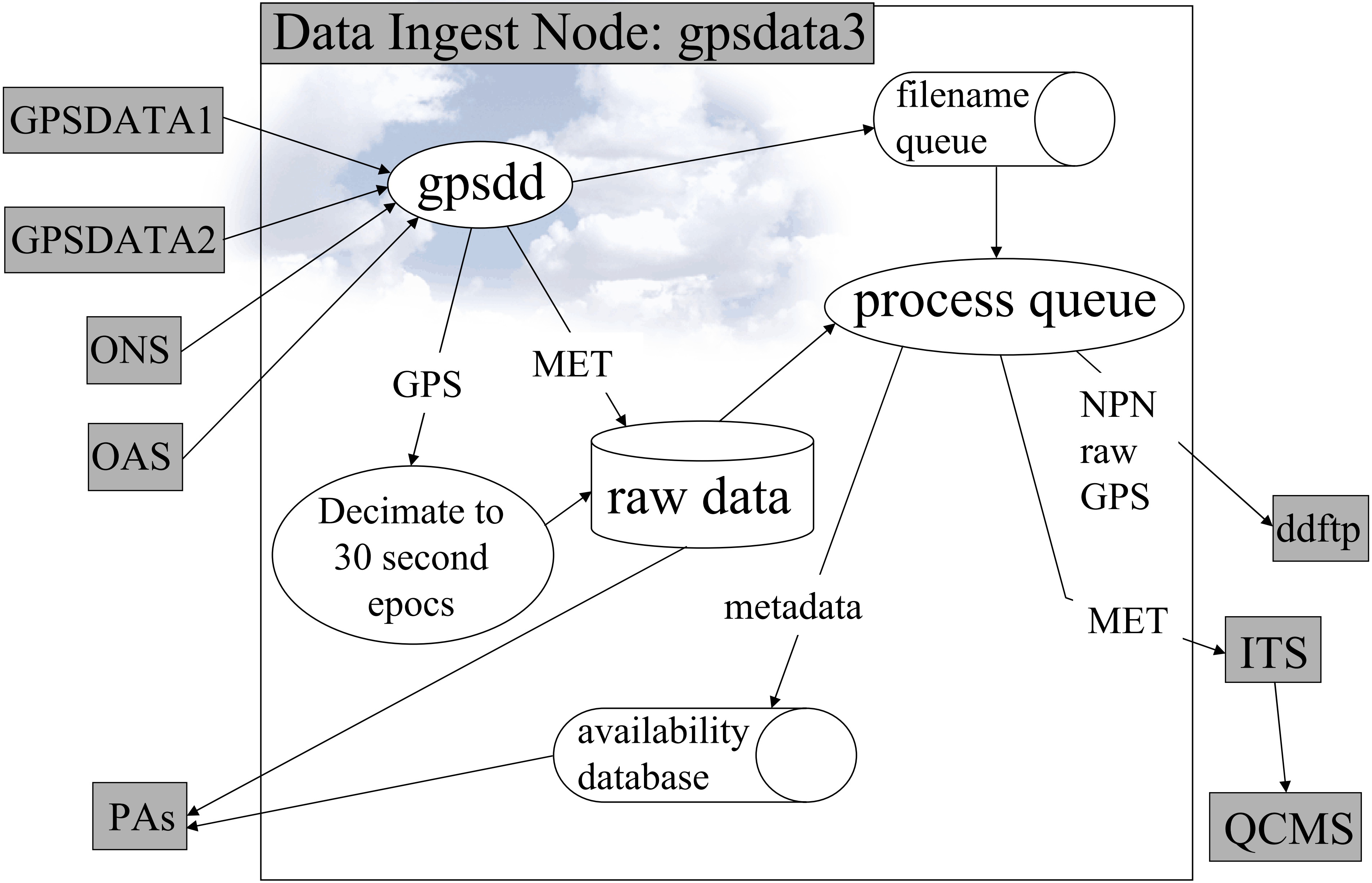
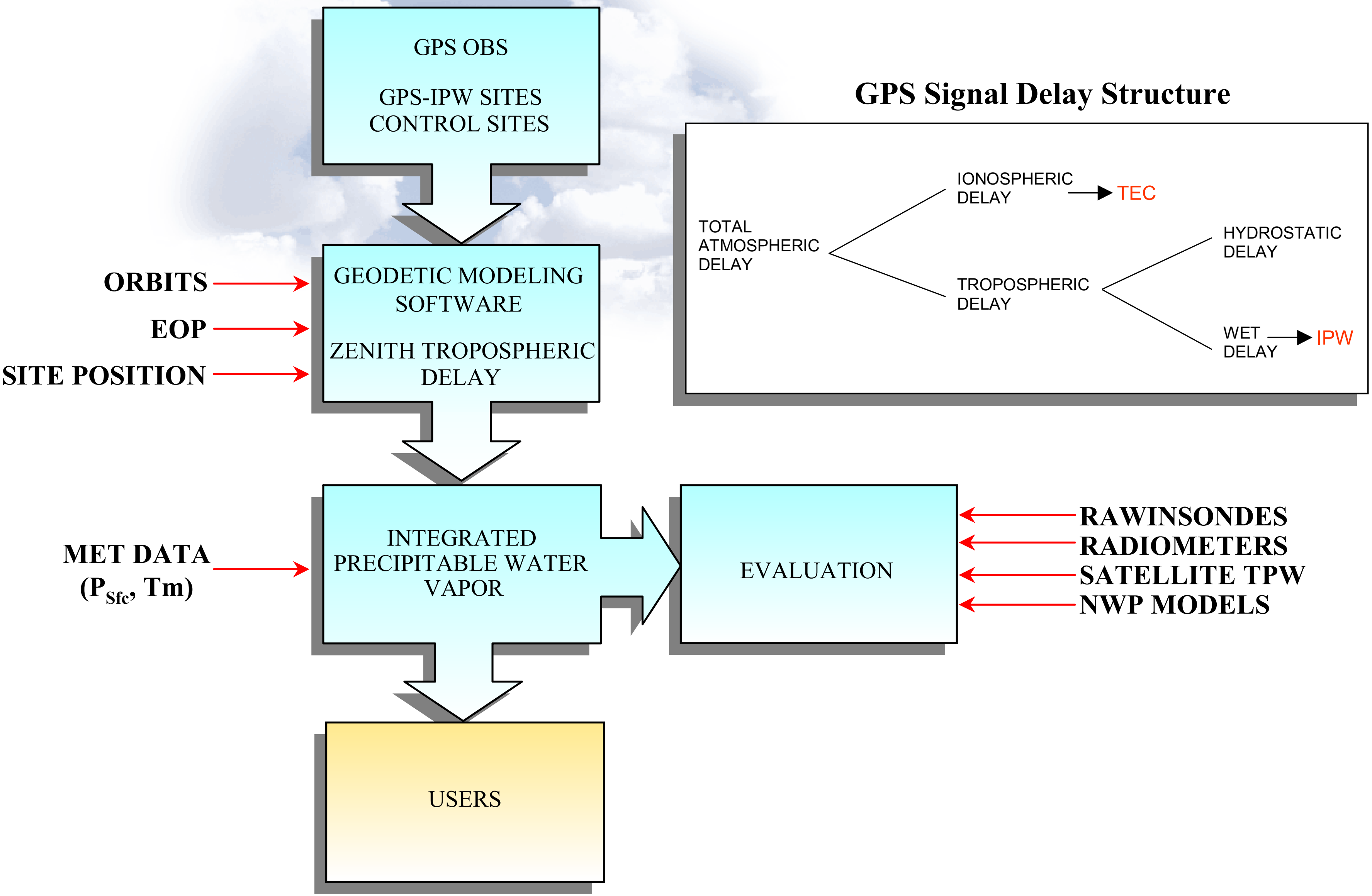
GPS-Met Data Acquisition & Processing Architecture



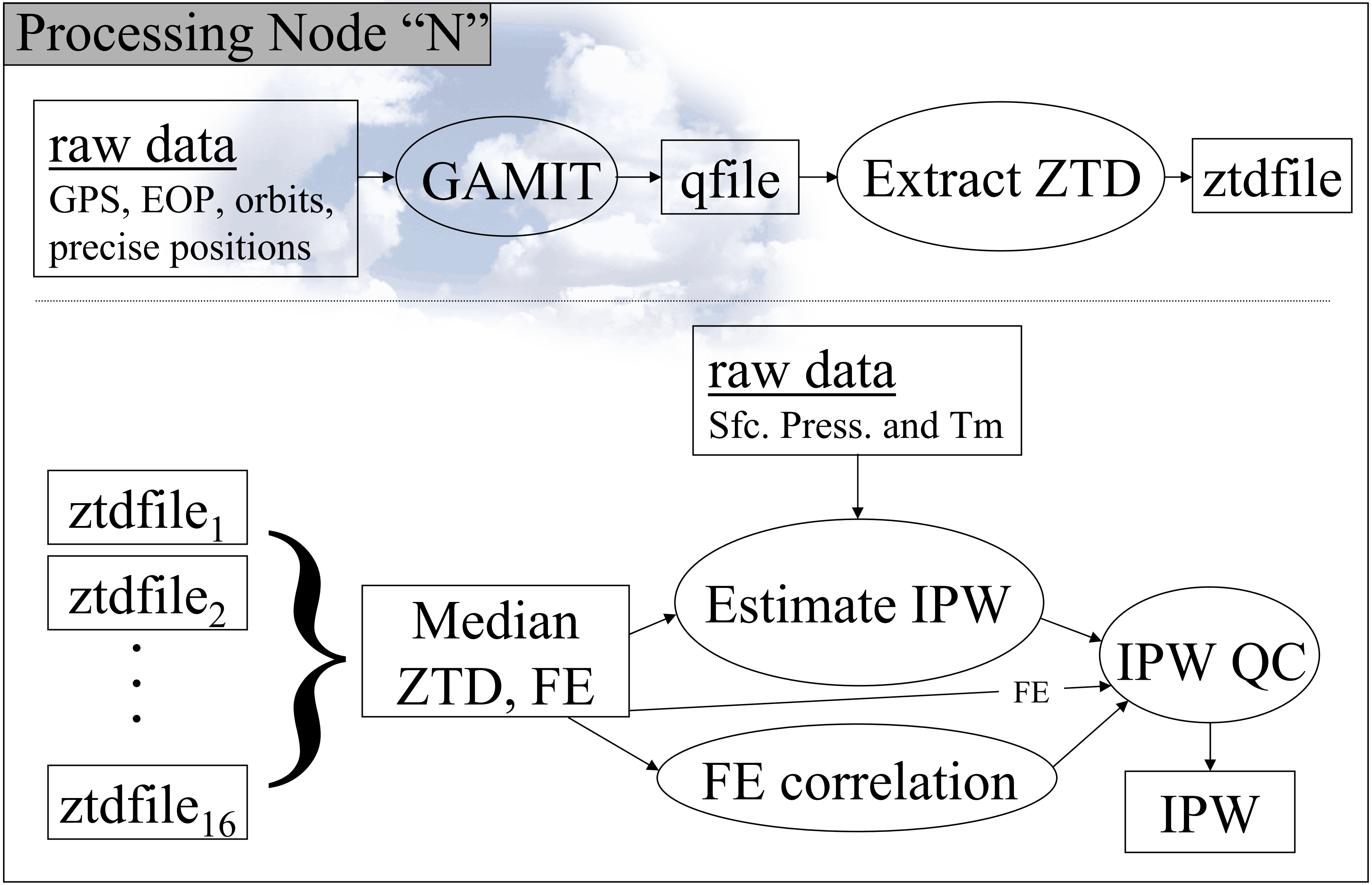
GPS-Met Data Ingest



Generalized GPS-Met Data Processing Scheme



GPS-Met PA Processing



Sliding Window Processing

- GPS observations are recorded in 30 minute blocks, designated as: (a, A) (b, B) (c, C) … (x, X). Block 'a' contains data for 00:00 to 00:30, 'A' for 00:30 to 01:00, …, 'x' for 23:00 to 23:30, and 'X' for 23:30 to 00:00

- Using these data files -> Estimate (ZTD, FE) for these times
- aA to hH > $ZTDFE_1$(00:15, 00:45, …, 07:15, 07:45)
- Ab to Hi > $ZTDFE_2$(00:45, 01:15, …, 07:45, 08:15)
- bB to iI > $ZTDFE_3$(01:15, 01:45, …, 08:15, 08:45)
- ….
- hH to oO > $ZTDFE_{15}$(07:15, 07:45, …, 14:15, 14:45)
- Hi to Op > $ZTDFE_{16}$(07:45, 08:15, …, 14:45, 15:15)

From $ZTDFE_1$ to $ZTDFE_{16}$ we have 16 estimates for ZTD and their corresponding FEs for time 07:45.

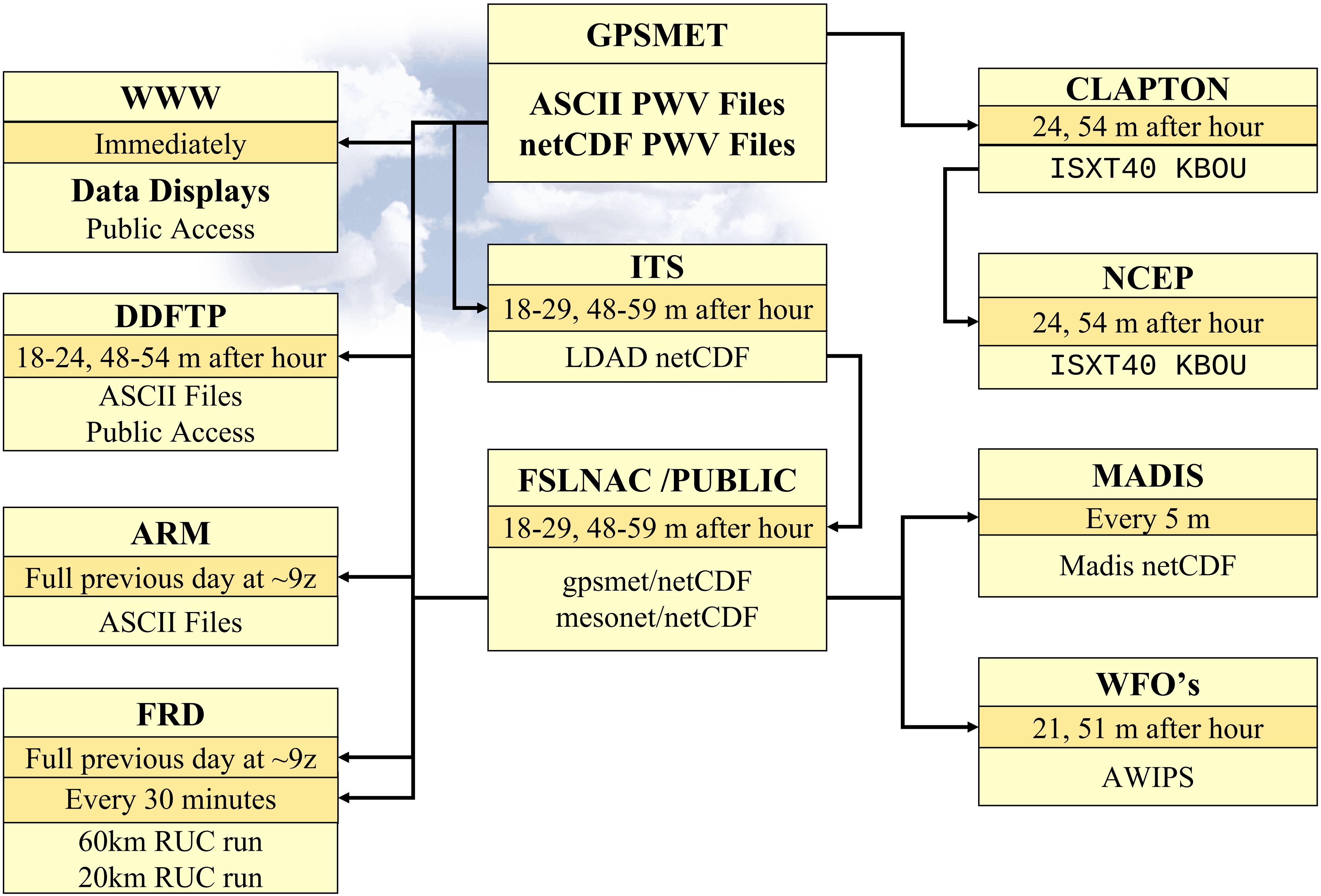
The estimate taken from ZTD_1 is designated to be the 'first' solution.

The 'final' solution is the median from the set ZTD_n(07:45); it is typically fully stabilized by estimate number 4.

Data Dissemination

- Raw (Trimble binary) GPS files from NPN sites are made available to NGS and UNAVCO by about 5 and 35 minutes after the hour
- MET data from NPN and Other Agency Sites (OAS) are available to ITS, NGS, and UNAVCO at 10 and 40 minutes after the hour
- IPW product is available to FSL every 30 minutes in ASCII, netCDF, and LDAD formats
- IPW product is also being provided to NCEP
- Quality control and product display pages are available on: http://gpsmet.noaa.gov/jsp/displays/display.jsp

Processed Data Distribution



Data Processing Hardware

- Currently using fifteen off-the-shelf PC systems, capable of processing about 150 sites.
- Architecture allows for easy expansion:
  - Implemented using the Linux operating system;
  - Low HW and SW cost per unit;
  - Relies on proven technology, but has several possible points of failure;
  - Risk mitigated by having 'hot spares' available.

Major Implementation Changes Since the April 2000 Tech Review

- An ‘availability’ database stores metadata about every GPS or MET file which has been ingested
  - The data are not stored in the data base
  - Metadata includes start and end times, file size, last modification time
- A ‘network’ database store metadata about each site
  - Metadata includes location, ownership, equipment installed
- System security has been enhanced
  - Telnet has been eliminated altogether
  - FTP has been eliminated where possible
  - IP ‘firewalling’ has been implemented on ‘routable’ internet hosts
- NTP is used to synchronize all clocks
  - Local system are typically within 1ms
  - Remote systems typically within 10 ms

Major Implementation Changes Since the April 2000 Tech Review

- WWW based system monitoring tools have been developed
  - Used by operators to help isolate failures
  - Following links allow operators to ‘drill down’ into the system and view data files and/or their metadata
  - Designed to provide a quick assessment of the system status from anywhere and at anytime
- A new user interface to the data has been developed
  - Allows data from RAOBS and/or UNB to be overlaid
  - Allows users to download data from an FTP site
  - Formats the plots for printing
- Generation of precise antenna positions:
  - Is now being performed at FSL
  - The positions generated are cross-checked against SOPAC solutions (if possible)

GPS-Met Project Home Page

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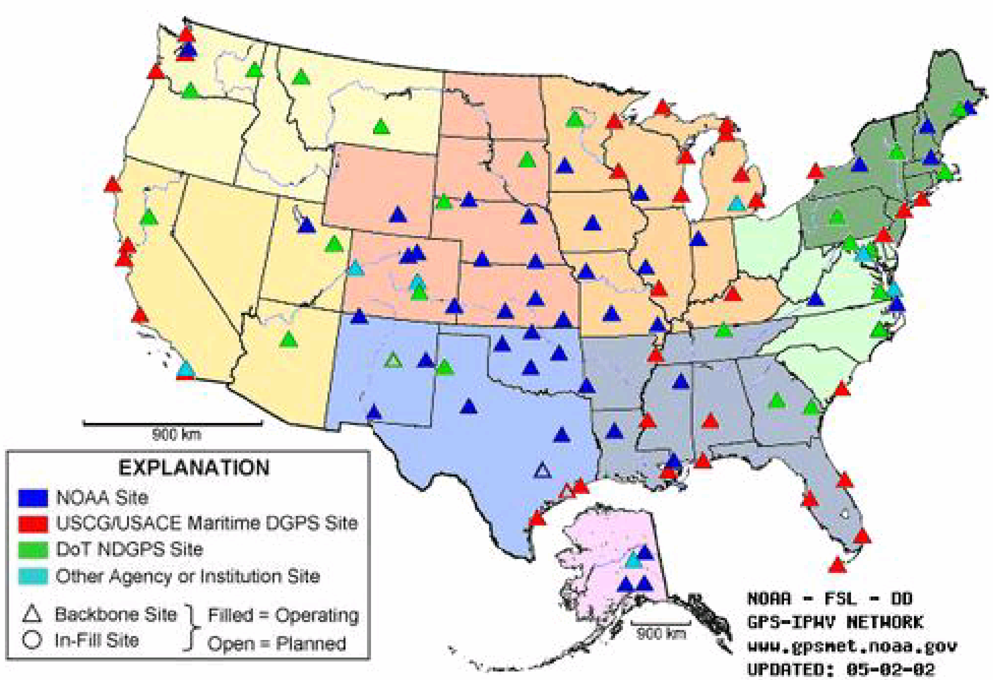
NOAA Forecast Systems Laboratory

Ground-Based GPS Meteorology Demonstration Network

(GPS-MET)

GPS-IPW Home | Background | Data Displays | Site Information | Links



The GPS-Met Observing Systems Branch develops and assesses techniques to measure atmospheric water vapor using ground-based Global Positioning System (GPS) receivers. The branch was formed in response to the need for improved moisture observations to support weather forecasting, climate monitoring, and research. The primary goals of the branch are to demonstrate the major aspects of an operational GPS integrated precipitable water vapor (IPWV) monitoring system, facilitate assessments of the impact of these data on weather forecasts, assist in the transition of these techniques to operational use, and encourage the use of GPS meteorology for atmospheric research and other applications.

2000 FSL/DD GPS-IPW Technical Review

[Forecast Systems Laboratory] [Demonstration Division] [Search FSL] [GPS Home]

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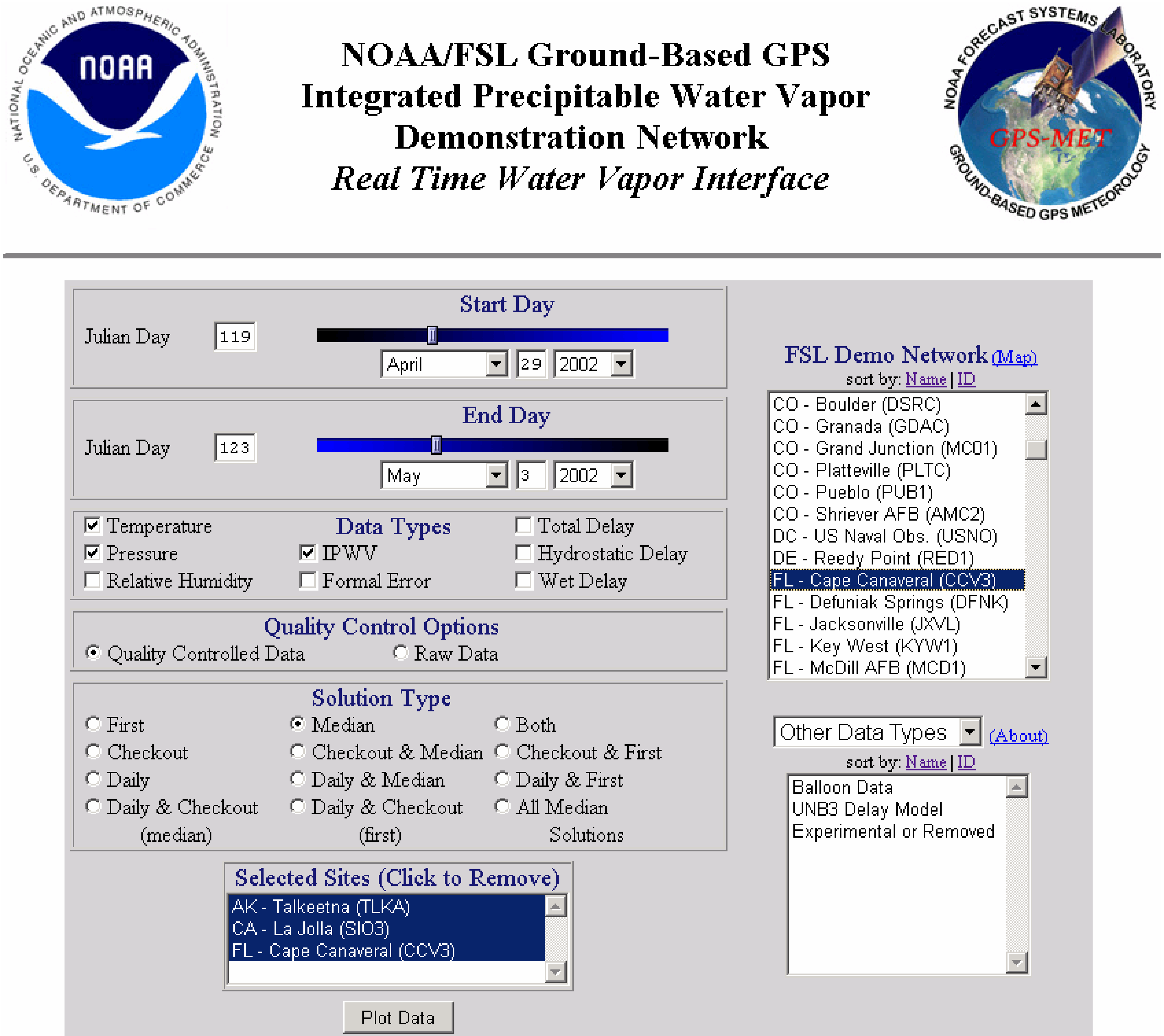
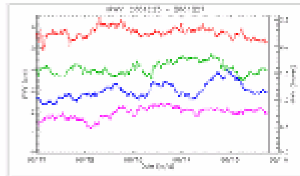

NOAA/FSL Ground-Based GPS
Integrated Precipitable Water Vapor
Demonstration Network
Real Time Water Vapor Interface
Start Day
Julian Day 119
April 29 2002
End Day
Julian Day 123
May 3 2002
Data Types
Temperature
Pressure
Relative Humidity
IPWV
Formal Error
Total Delay
Hydrostatic Delay
Wet Delay
Quality Control Options
Quality Controlled Data
Raw Data
Solution Type
First
Checkout
Daily
Daily & Checkout (median)
Median
Checkout & Median
Daily & Median
Daily & Checkout (first)
Both
Checkout & First
Daily & First
All Median Solutions
Selected Sites (Click to Remove)
AK - Talkeetna (TLKA)
CA - La Jolla (SIO3)
FL - Cape Canaveral (CCV3)
Plot Data
FSL Demo Network (Map)
sort by: Name | ID
CO - Boulder (DSRC)
CO - Granada (GDAC)
CO - Grand Junction (MC01)
CO - Platteville (PLTC)
CO - Pueblo (PUB1)
CO - Shriever AFB (AMC2)
DC - US Naval Obs. (USNO)
DE - Reedy Point (RED1)
FL - Cape Canaveral (CCV3)
FL - Defuniak Springs (DFNK)
FL - Jacksonville (JXVL)
FL - Key West (KYW1)
FL - McDill AFB (MCD1)
Other Data Types (About)
sort by: Name | ID
Balloon Data
UNB3 Delay Model
Experimental or Removed

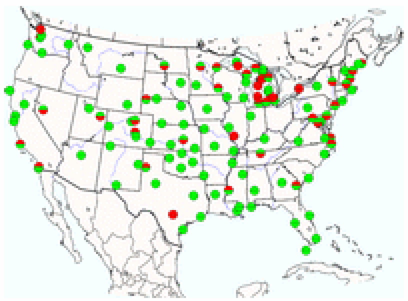
NOAA Forecast Systems Laboratory

Ground-Based GPS Meteorology Demonstration Network

Real Time Data Displays

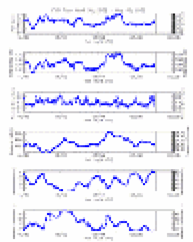
View precipitable water vapor measurements
and associated data by clicking this icon.
These data have a latency of approximately 55 minutes.
Data for the time 00:15 (0 hours and 15 minutes) are usually available by 00:55. Data are normally updated at about 25 and 55 minutes after the hour and they represent the time periods hh:15 and hh:45, where hh is the current hour.

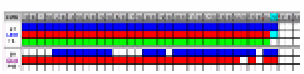




View the real-time data collection status board
by clicking this icon.
These data have a latency of approximately 20 minutes.
Data for the period 00:00 to 00:30 are available by 00:50
Data are normally updated twice per hour, at 20 and 50 minutes.
This page will automatically refresh a few minutes after each update.

View seven-day time IPW and MET time series
by clicking this icon.
These data are refreshed once per day.
Data are normally updated by 11:00 UTC each day.



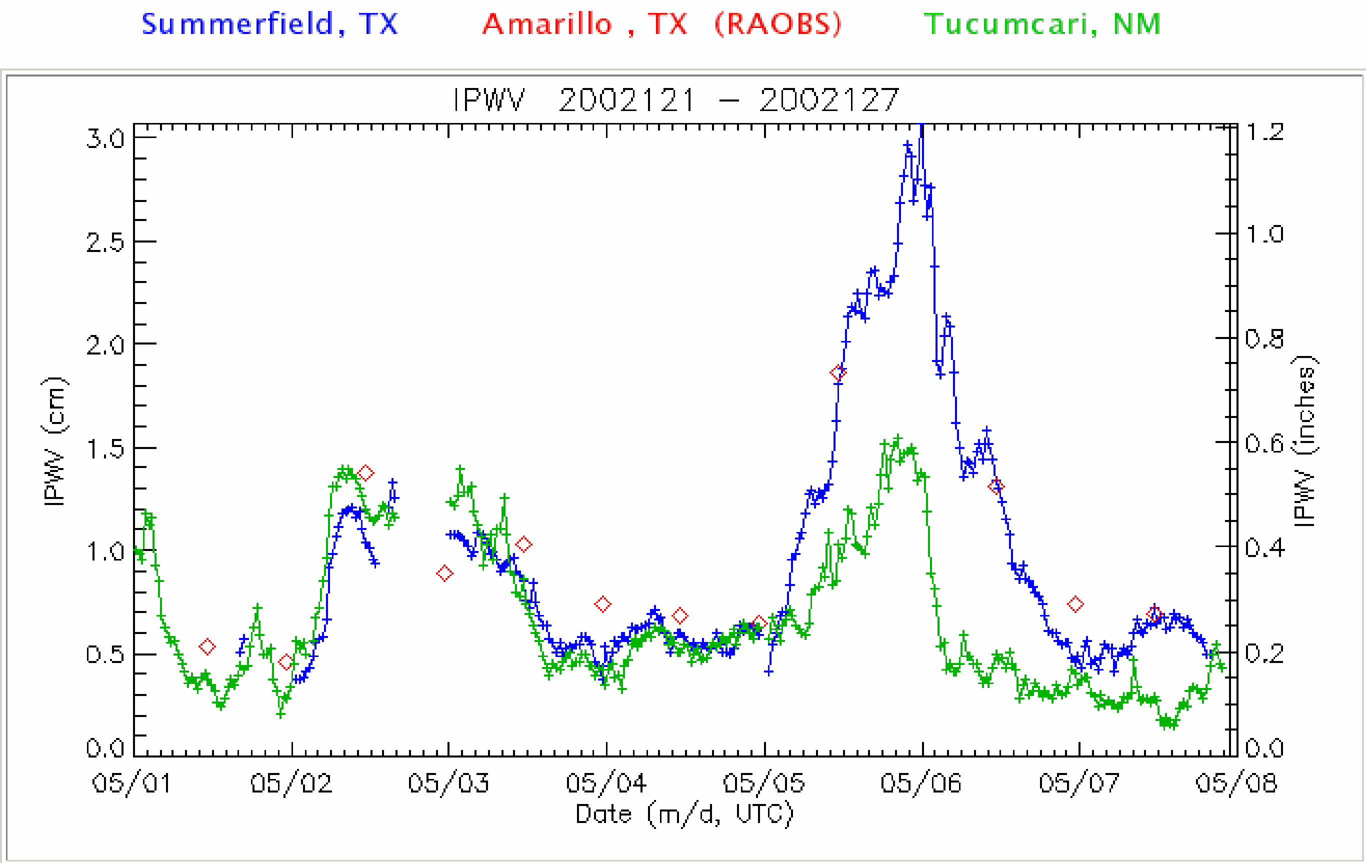


View the status of our real-time processing system
system by clicking the icon on this icon.
These data have a latency of approximately 25 minutes.

IPW Time Series Display

The plot below show the integrated precipitable water vapor estimate for the near real time solution and the corresponding meteorological measurements. The current time is Tuesday, May 7, 2002 10:50:33 PM and it is marked by the vertical line. Click on the Download button below to obtain a text version of the data.

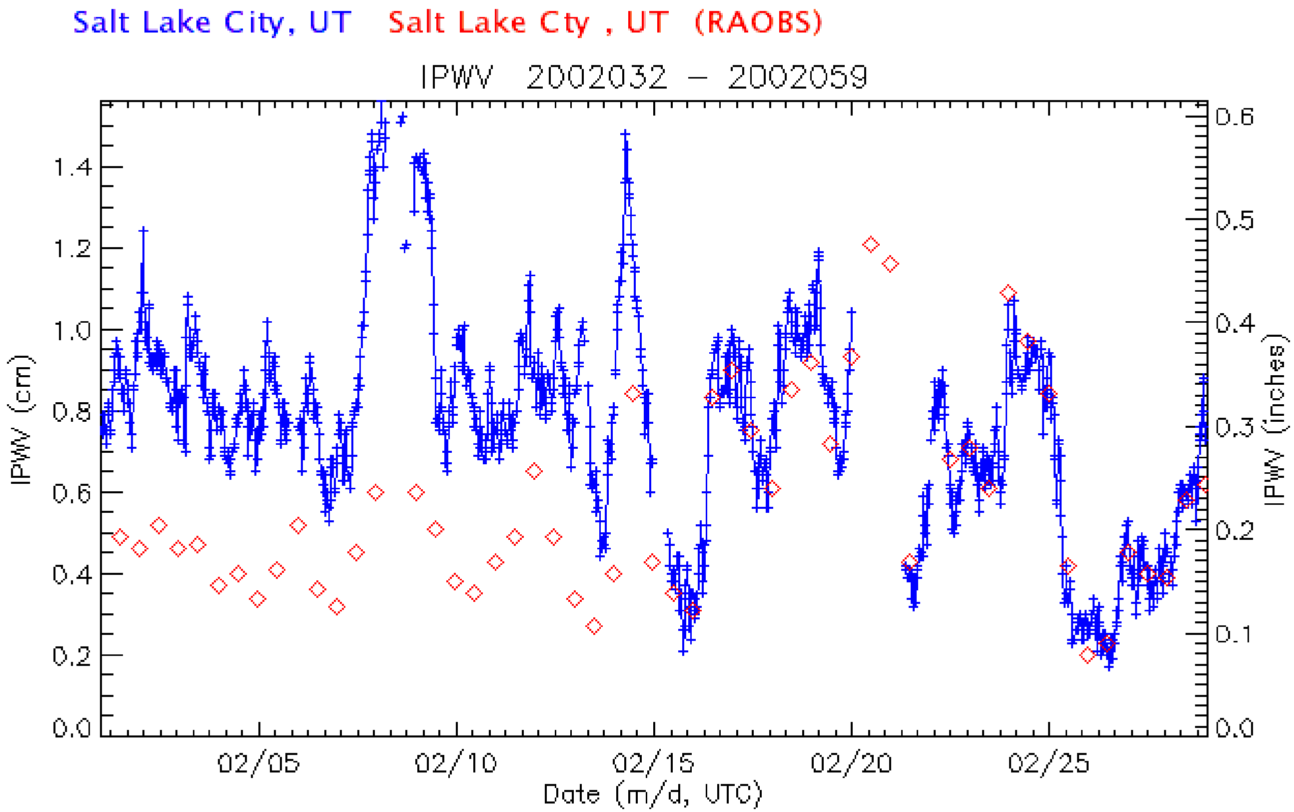
Download   Print Format   GOES IMAGERY AND PRODUCTS



Goto Links to Current PWV and MET Data

Goto GPS-IPW Interactive Display

RAOB Data & IPW QC



- Comparisons between raob integrated moisture soundings and GPS-IPW retrievals have always been the primary means of evaluating GPS-Met.
- Initially, we used NWS sonde data available on the web from University of Wyoming for this purpose. We now use U. Wyoming as a backup.
- In 2001, we started acquiring our NWS sonde data from /public.

Acknowledgement to Tom Schlatter, Stan Benjamin, and Barry Schwartz.

Forecast Systems Laboratory
Boulder, Colorado

Data Visualization

- Use FX-Net to prototype workstation displays:
  - Point data observations;
  - Contoured data;
  - Images.
- Use a high resolution mesoscale analysis containing GPS-IPW to portray the PWV field:
  - LAPS WIAP 13-km total precipitable water (TPW) analysis selected;
  - Other grids from other models can also be used.

Acknowledgements: R. Brummer, S. Madine & J. Pyle (FX-Net integration); D. Birkenheuer, J. Smart & B. Shaw (LAPS WIAP analysis); L.Wharton & A. Stanley (WIAP grid availability);

Data Visualization Using FX-Net

Jet

- LAPS processing creates WIAP file containing total precipitable water (TPW) grid
- Creates AWIPS netCDF file containing TPW.

AWIPS netCDF

AWIPS
Data Server

NFS

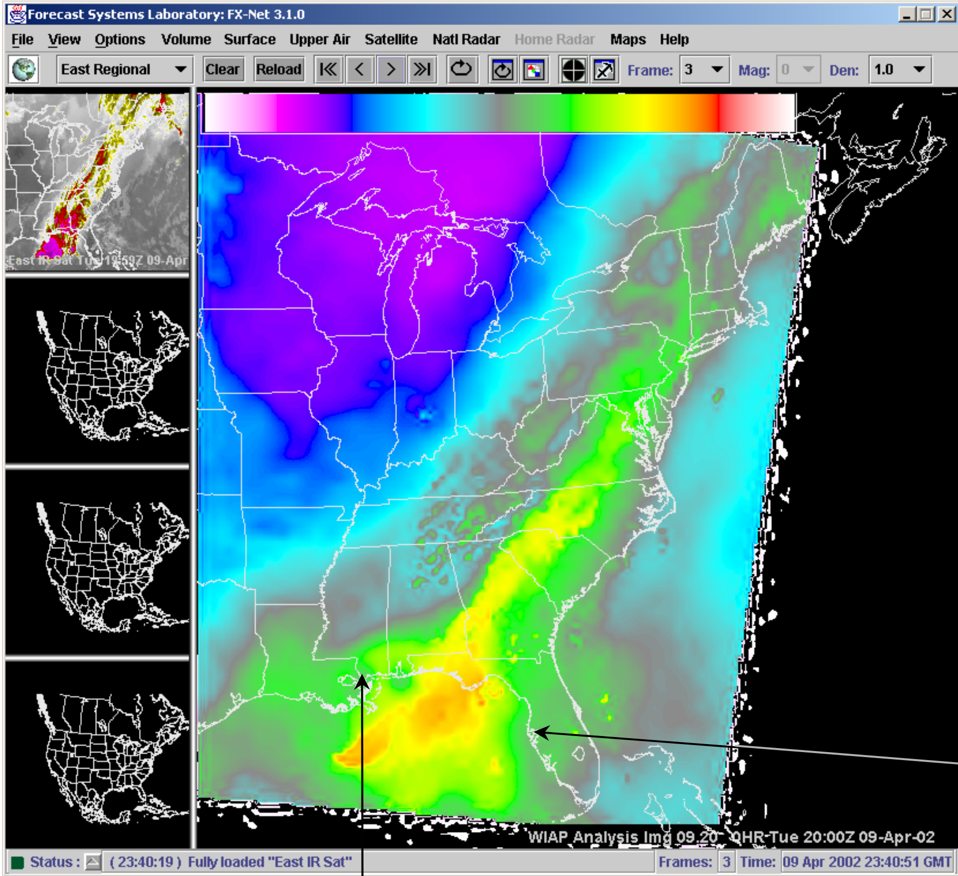
FX-Net Server

(produces displayable products)

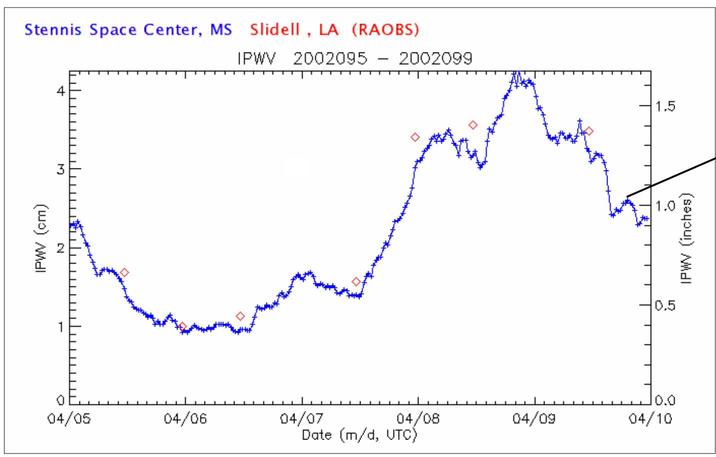
WIAP

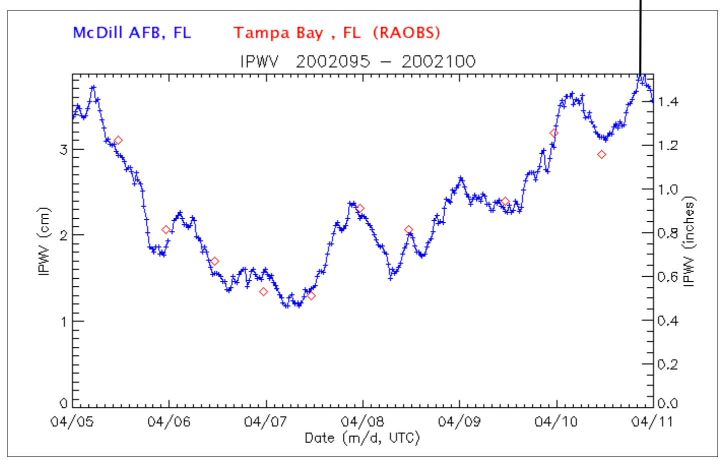
FX-Net
Client

Data Visualization Using FX-Net



WIAP 13km PWV Analysis w/GPS-Met





Plans/Problem Mitigation Strategies

- With the introduction of the FSL firewall, the WWW server gpsmet.noaa.gov will be moved into DMZ and replicated behind the filewall
- The HTML-based displays need to be replaced using technologies which are more scalable with the number of sites in the network
- As the number of PAs increase NFS may become unstable or too slow. Correcting this situation would require a reengineering of the ‘raw data’ service
- The concept of using formal error correlations as an orbit quality control metric needs to be parameterized
    - How many stations are necessary and/or required?
    - What is the ‘best’ group of sites to use?

FORECAST SYSTEMS LABORATORY
BOULDER, COLORADO

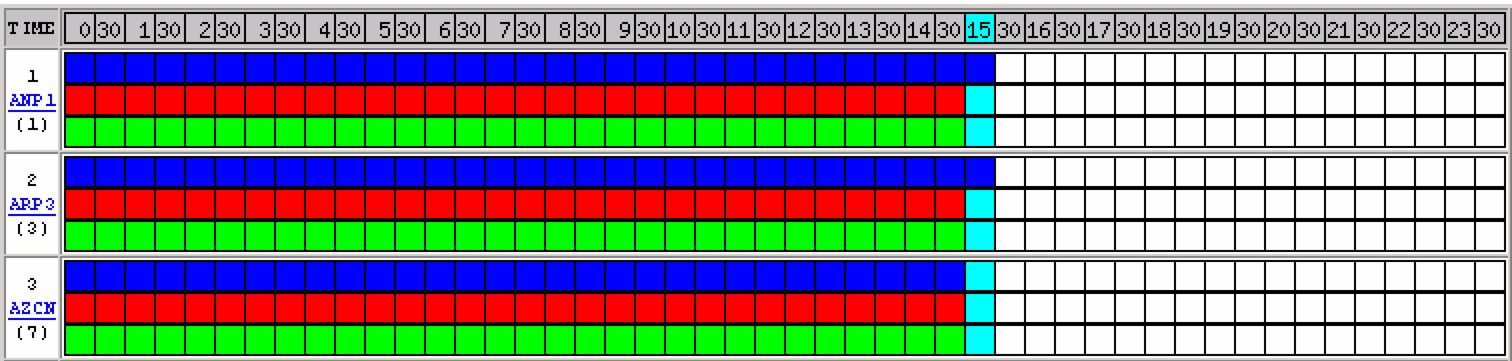
Data Acquisition and Processing Display

NOAA/FSL Ground-Based GPS Integrated Precipitable Water Vapor Demonstration Network
JDay 02101 Data Collection and Processing Status

The plots below provide a qualitative assessment of the GPS, MET, and PWV data which have been collected or produced by the GPS-IPW system for the Julian day indicated. This page will automatically refresh about one minute after each update.

Data are shown for 48 half-hour sampling periods. These periods are 0000, 0030, ...,2300, 2330. GPS data which have been received are colored **blue**. MET data which have been received are colored **red**. PWV data which have been produced are colored **green**. The current time is shown in **cyan**

Created on 02101 at 15:33:37 and refreshed on 02101 at 15:33:56
Today is Thu Apr 11 15:33:37 GMT 2002



Data Acquisition and Processing Display
GPS Ingest File Listing

Tue May 7 15:54:47 GMT 2002
Result of ls -lr /data/rawdata/2002/127/dsrc/dsrc*02o*

mon	d	hh:mm	size	hour	link to file
May	7	15:33	15246	15	/data/rawdata/2002/127/dsrc/dsrc127p.02o.gz
May	7	15:03	28050	14	/data/rawdata/2002/127/dsrc/dsrc127o.02o.gz
May	7	14:03	32139	13	/data/rawdata/2002/127/dsrc/dsrc127n.02o.gz
May	7	13:03	31916	12	/data/rawdata/2002/127/dsrc/dsrc127m.02o.gz
May	7	12:03	28511	11	/data/rawdata/2002/127/dsrc/dsrc127l.02o.gz
May	7	11:43	30977	10	/data/rawdata/2002/127/dsrc/dsrc127k.02o.gz
May	7	10:03	34656	9	/data/rawdata/2002/127/dsrc/dsrc127j.02o.gz
May	7	09:03	34013	8	/data/rawdata/2002/127/dsrc/dsrc127i.02o.gz
May	7	08:03	33223	7	/data/rawdata/2002/127/dsrc/dsrc127h.02o.gz
May	7	07:03	32599	6	/data/rawdata/2002/127/dsrc/dsrc127g.02o.gz
May	7	06:03	30129	5	/data/rawdata/2002/127/dsrc/dsrc127f.02o.gz
May	7	05:03	31075	4	/data/rawdata/2002/127/dsrc/dsrc127e.02o.gz
May	7	04:03	32300	3	/data/rawdata/2002/127/dsrc/dsrc127d.02o.gz
May	7	03:03	28817	2	/data/rawdata/2002/127/dsrc/dsrc127c.02o.gz
May	7	02:03	31836	1	/data/rawdata/2002/127/dsrc/dsrc127b.02o.gz
May	7	01:03	35341	0	/data/rawdata/2002/127/dsrc/dsrc127a.02o.gz

View boulder's GPS Status.

View boulder's GPS Table of Contents.

View boulder's downloaded r00 files on gpsdsrc.

Data Acquisition and Processing Display

- Displays data ingest and IPW processing status
  - Divided into the 48 half-hour times periods
  - Blue represents GPS data ingest
  - Red represents MET data ingest
  - Green represents IPW estimates completed
- Blue, red, and green regions are linked to additional displays which provide more detail
- Site ID is linked to a ‘quick look’ time series
- Rebuilt whenever new data in acquired or generated and ‘pulled’ by the browser with 2 ½ minutes

Data Acquisition and Processing Display
GPS PLT File

PLT file for dsrc127e.02o.gz contains:

```
 SV+------------------------------------------------------------------------+ SV
  30|oooooooooo2,,Iooooo,,moooooooo,I,                                       | 30
  11|ooooooooooooooooooooooooooooooooooo2oooooooooooo,,I,,,Io                | 11
  20|oooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooo| 20
  14|oooooooooooooooooooooooooooooooooooooooooooooooooooooooooo1,Ioo22ooooooo| 14
   2|ooooooooooooooooooooooooo,Iooooooooooooooooooooooooooooooooooooooooooooo|  2
  25|oooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooo| 25
  22|oooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooo| 22
   1|oooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooo|  1
   4|                                      ,,,,  ,,,   ,,,  ,,,,,,, ,,, ,,,,I|  4
  13|                                       ,,,,,,,,,I2oooooooooooooooooooooo| 13
 Obs|888888888888888888888888888888887777789998899988899988999888888888788888|Obs
 Clk|                 +                                      +               |Clk
    +------------|-----------|-----------|-----------|-----------|-----------+
 04:00:00.000                                                       04:59:30.002
 2002 May  7                                                         2002 May  7

*********************
 QC of RINEX  file(s) : dsrc127e.02o
*********************

 Time of start of window : 2002 May  7  04:00:00.000
 Time of  end  of window : 2002 May  7  04:59:30.002
 Time line window length : 59.50 minute(s), ticked every 10.0 minute(s)
 Observation interval    : 30.0000 seconds
 Total satellites w/ obs : 10
 NAVSTAR GPS SVs w/o OBS :  3   5   6   7   8   9  10  12  15  16  17  18
                           19  21  23  24  26  27  28  29  31  32
 Rx tracking capability  : 12 SVs
 Poss. # of obs epochs   :    120
 Epochs w/ observations  :    120
 Complete observations   :    881
  Deleted observations   :     77
 Moving average MP1      : 0.537751 m
 Moving average MP2      : 0.885949 m
 Points in MP moving avg : 50
 No. of Rx clock offsets : 2
 Total Rx clock drift    : +2.000000 ms
 Rate of Rx clock drift  : +2.017 ms/hr
 Avg time between resets : 29.750 minute(s)
 Report gap > than       : 10.00 minute(s)
        but < than       : 90.00 minute(s)
 epochs w/ msec clk slip : 0
 other msec mp events    : 1 (: 26)   {expect <= 1:50}
```

Click here to view a description of the symbols used on the ASCII SV versus time plot

Click here to view the GPS RINEX file dsrc127e.02o.gz

Forecast Systems Laboratory
Boulder, Colorado

Data Acquisition and Processing Display
GPS Receiver Status

GPS reciever status from boulder as of Tue May 7 15:57:28 GMT 2002

```
5700-RC REMOTE CONTROL, v2.51 TEST Linux (Mar 30 2001)
 Copyright (c) 1993-2001 Trimble Navigation Limited.  All rights reserved.
 /home/auto/bin/rstatus, 2.26
 Could not find "serial_port", creating...
 Storing new device file name (/dev/boulder_gps).
 CRTSCTS is Disabled
 Port initialized (4800 baud, 8 data bits, None, 1 stop bit)
 Testing communications link...wait.
 Testing receiver configuration
 Connection established.
 ***** RSTATUS BEGIN TRACKING

 SV30  AZ:312  ELV:26  SNR(L1):11.3  SNR(L2):  6.38
 SV24  AZ:230  ELV:82  SNR(L1):23.0  SNR(L2): 22.46
 SV09  AZ:236  ELV:25  SNR(L1):10.7  SNR(L2):  5.39
 SV04  AZ: 47  ELV:52  SNR(L1):20.7  SNR(L2): 19.72
 SV05  AZ:300  ELV:54  SNR(L1):20.4  SNR(L2): 20.01
 SV10  AZ:172  ELV:13  SNR(L1): 4.1  SNR(L2):  1.49
 SV07  AZ: 88  ELV:20  SNR(L1): 9.3  SNR(L2):  4.66
 ***** RSTATUS END TRACKING

 ***** RSTATUS BEGIN LOGGING

 SV30  CONT(L1):    56  CUMUL(L1):    56  CONT(L2):    56  CUMUL(L2):    56
 SV24  CONT(L1):    56  CUMUL(L1):    56  CONT(L2):    56  CUMUL(L2):    56
 SV 9  CONT(L1):    56  CUMUL(L1):    56  CONT(L2):    56  CUMUL(L2):    56
 SV 4  CONT(L1):    56  CUMUL(L1):    56  CONT(L2):    56  CUMUL(L2):    56
 SV 5  CONT(L1):    56  CUMUL(L1):    56  CONT(L2):    56  CUMUL(L2):    56
 SV10  CONT(L1):    24  CUMUL(L1):    46  CONT(L2):     8  CUMUL(L2):    19
 SV 7  CONT(L1):    56  CUMUL(L1):    56  CONT(L2):    56  CUMUL(L2):    56
 ***** RSTATUS END LOGGING

 Done.
 ***** RSTATUS BEGIN STATE

 SURVEY STATE: LOGGING
 SVS LOCKED      : 07
 BATTERY         : 100%
 MEMORY REMAINING: 0223 hours
 RECVR STATUS    : Static survey measurements.
 ***** RSTATUS END STATE
```

FORECAST SYSTEMS LABORATORY
BOULDER, COLORADO

System Status Display

NOAA/FSL Ground-Based GPS Integrated Precipitable Water Vapor Demonstration Network
System Status

Created: Thu Apr 11 15:24:32 GMT 2002
Last Refreshed: Thu Apr 11 15:27:10 GMT 2002

gpsmet (12 days, 20:09) 0.217 1.94 9 89%	**gpsdata1** (7 days, 23:51) 0.269 0.46 6 82%	**gpsdata2** (47 days, 17:42) 0.058 0.01 1 70%	**gpsdata3** (12 days, 13:22) -0.650 0.76 7 70%	**gpspa1** (47 days, 17:39) 1.098 0.90 5 67%	**gpspa2** (47 days, 17:44) -0.200 0.04 3 70%	**gpspa3** (47 days, 17:45) -0.604 0.01 2 70%	**gpspa4** (47 days, 17:44) -0.527 0.00 3 70%	**gpspa5** (47 days, 17:43) -0.565 0.03 3 70%	**gpspa6** (47 days, 17:44) -0.661 0.05 4 70%
gpspa7 (47 days, 17:35) -0.435 0.21 3 67%	**gpspa8** (36 days, 22:18) 1.349 0.48 3 67%	**gpspa9** (13 days, 17:22) 0.543 0.91 4 67%	**gpspa10** (47 days, 17:09) 1.122 0.43 3 67%	**gpspa11** (47 days, 17:32) 0.130 0.22 3 67%	**gpspa12** (47 days, 17:35) -0.331 0.18 3 67%	**gpspa13** (42 days, 16:37) -1.196 0.21 2 67%	**gpspa14** (47 days, 17:33) -0.589 0.20 3 67%	**gpspa15** (47 days, 17:34) -0.602 0.13 2 67%	**gpsamc2** (2 days, 3:18) -8.236 0.01 4, 4, 3, 3, 4 21%
gpsblkv (154 days, 20:44) -18.993 0.08 6, 6, 4, 4, 11 41%	**gpscovx** (64 days, 20:45) 19.464 0.08 3, 2, 2, 3, 2 70%	**gpsdsrc** (16 days, 19:46) 0.085 0.08 3 39%	**gpsnfln** (12 days, 15:43) 36.143 0.00 13, 6, 7, 3, 3 21%	**gpsmdot** (4 days, 22:06) -1.748 0.01 8 68%	**gpsndbc** (26 days, 1:21) -1.107 0.01 2, 2, 3, 3, 2 23%	**gpsseaw** (62 days, 10:41) -0.215 0.09 10 92%	**gpsslcu** (168 days, 19:09) 2.431 0.04 2, 3, 2, 2, 5 16%	**clapton** (47 days, 18:15) -0.707 0.09 3 29%	**dddatabase** (55 days, 19:23) 0.208 0.00 2 88%
ddftp (37 days, 21:37) 0.633 0.10 3 75%	**page** (19 days, 20:48) 1.139 0.22 2 92%	**vaughn** (30 days, 15:44) -0.191 0.11 3 92%							

System Status Display

- Displays five critical pieces of information at a glance
  - System uptime
  - Clock offset
  - Number of jobs in the run queue
  - Most filled file system
  - Time required to gather all information
- Continuously updated
  - Normally requires 1 to 2 minutes to cycle through hosts
  - Web page is 'pulled' by the browser every 2.5 minutes
- Could be easily modified to report additional information
- Developed for GPS-Met project, but also used by NPN (Linux) production hosts as well

netCDF Roundtrip Display

- We can track the progress of our data from when the netCDF files are first created on GPSMET, to the Madis netCDF files.

Round trip report for gpsmet files:

NETCDF Roundtrip File Statistics

File : /data/publicdata/gpsmet/netcdf/0212212450030o.nc
Report Creation Time: 2002 05 02 - 15:16:41
Oldest Data in file: 2002 05 02 - 12:45:00
Most Recent Data in file: 2002 05 02 - 12:45:00

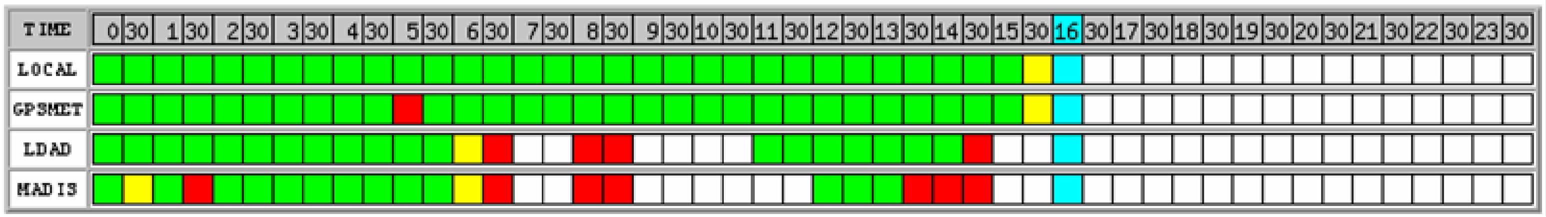
Half Hour Stats:

95.93 percent complete
- 118 of 123 sites included

Missing Sites:
barn
mc01
pnr1
stl4
whd1

Data availability greater than 85% are colored **green**. Data availability greater than 50% are colored **yellow**. Data availability less than 50% are colored **red**. The current time is shown in **cyan**

Created on 02127 at 16:39:01 and refreshed on 02127 at 16:40:29
Today is Tue May 7 16:39:01 GMT 2002



Forecast Systems Laboratory
Boulder, Colorado

Processing Array Configuration

- Centrally Managed Processing array system
- Restricted access by IP address
- Allows selection of subnet to process, and publish path for each individual processing node
- Before each processing cycle, these values are updated on each Processing Node.

Processing Array Configuration

Must use Commit Changes Button to Save Work
Processing Nodes will update at 28 and 58 after the hour

Current Publish Paths

Name	Type	Location
halted	MODE	auto@gpsmetlocal:path
checkout	CHECKOUT	auto@gpsmetlocal:/data/rt
release	RELEASE	auto@gpsmetlocal:/data/rt
release2	RELEASE	auto@gpsmetold:/data/rt/
daily	DAILY	auto@gpsmetlocal:/data/rt

Current Node Arrangement

Processing Node	Node Subnet	Node Publish Path
GPSPA9	a	release
GPSPA15	1	release halted checkout release release2 daily
GPSPA14	2	
GPSPA13	3	
GPSPA12	4	release

FORECAST SYSTEMS LABORATORY
BOULDER, COLORADO

Site Information Editor

Editing Boulder, CO

Last modified: Fri Feb 22 18:34:56

Identification

Name: Boulder, CO ID: DSRC Site Number: GPS020

Site Type: ONS Agency: NOAA/FSL/DD Observer: NOAA/FSL/DD

Installed: 28-May-99 Removed: DD-MON-YYYY

Receiver

Receiver Type: TRIMBLE 4000 SSI Antenna Type: Trimble L1/L2 Micro Centered [TRM33429.00+GP]

Software Version: 7.19 Receiver Serial Number: 3327A03457 Antenna Serial Number: 0220132576

DOCN: N/A

GPS to MET height offset (meters -- down is positive): 0.26 Antenna Height: 1.7340

MET Payload

Payload Type: GSOS DOCN: N/A Serial Number: GSOS 031 Software Version: 2.1d

SLP Coefficients: A: 0 B: 1.2246917 C: -0.00054073 D: 0.00000293

Location

Latitude: 39.99143102 Longitude: -105.2610319 Ellipsoid Height: 1654.5739

Geoid: -15.662 Orthometric Height: 1670.2359

Both **Geoid** and **Orthometric Height** are calculated after
Latitude, Longitude, and Ellipsoid Height are Entered and Updated

Site Information History

Update History
Lamont, OK -- LMNO2

Update Summary

```
Tue Nov 20 17:11:56
  **-> Receiver Serial Number
Mon Oct  1 18:50:11
  **-> Receiver Type, Receiver Software Version, Receiver Serial Number, Antenna Serial
Number, Antenna Height, METPayload Type, GSOS Serial Number, Location(Latitude,
Longitude, Elliptic Height, Orthometric Height)
```

Receiver Type	Used Through
TRIMBLE 4000 SSE	Current
TRIMBLE 4000 SSE	Mon Oct 1 18:50:11

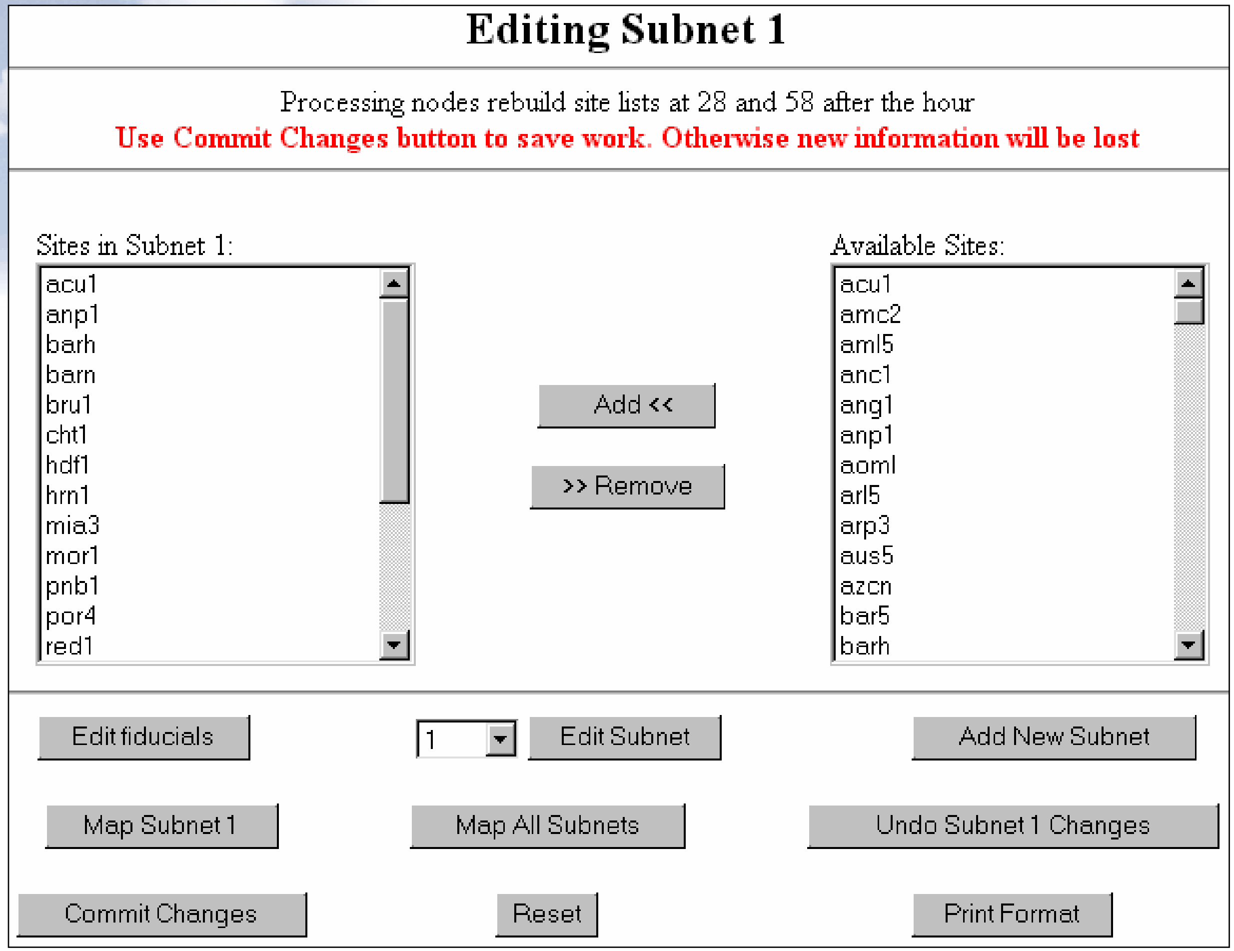
Location					Used Through
Latitude	Longitude	Orthometric Height	Elliptic Height	Geoid	
36.68544633	-97.48073677	306.3792	278.0002	-28.379	Current
36.68544637	-97.48073669	306.3706	277.9916	-28.379	Mon Oct 1 18:50:11

Receiver Software Version	Used Through
7.19	Current
7.29	Mon Oct 1 18:50:11

Receiver Serial Number	Used Through
3503A09384	Current
3832A23783	Tue Nov 20 17:11:56
N/A	Mon Oct 1 18:50:11

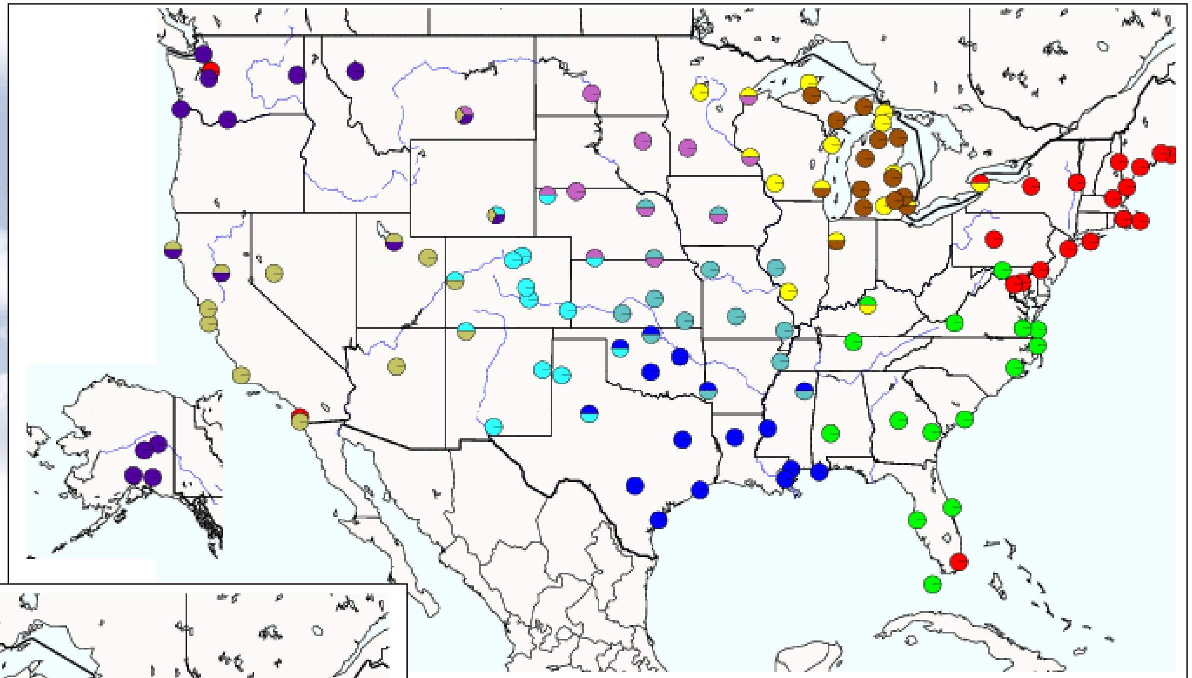
Subnet Configuration

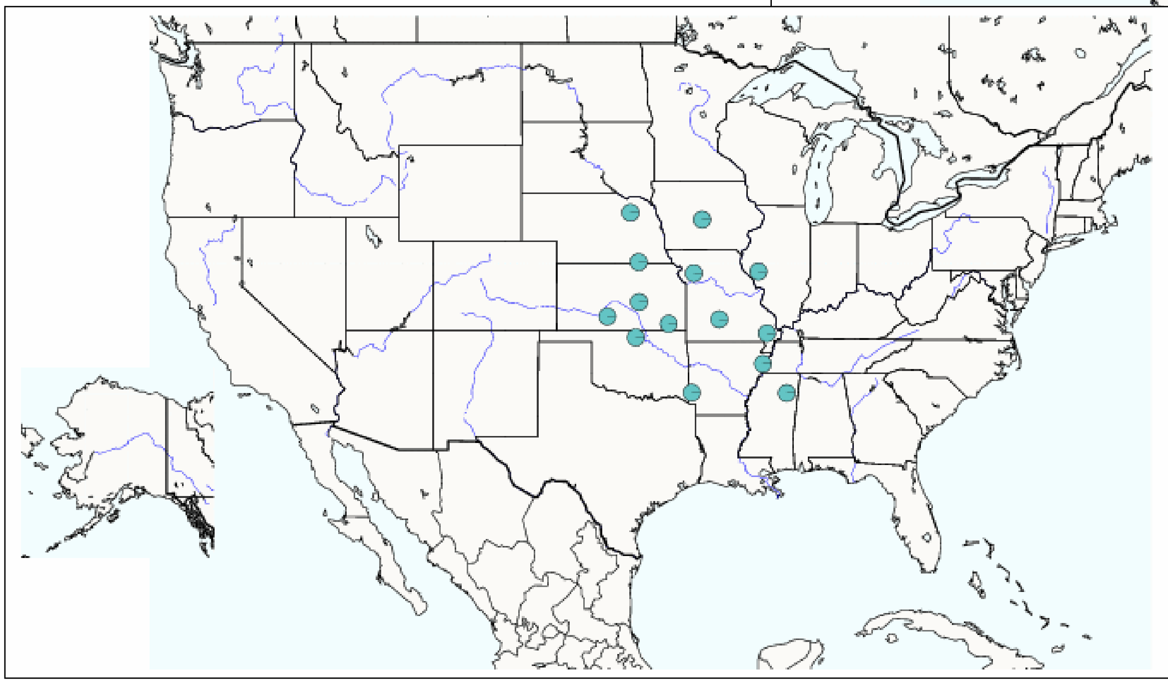
- Edit individual subnets and fiducials points
- Allows display of subnets before committing changes
- Processing arrays update information before every processing cycle



Subnets Display

- Display tools to map all subnets – or just one.
- Easy to see site distribution throughout subnets





Subnet 1	Subnet 2
Subnet 5	Subnet 6
Subnet 9	Subnet a
Subnet 3	Subnet 4
Subnet 7	Subnet 8
Subnet b	Subnet c

Surface Pressure at In-Fill Sites

- How far can a pressure measurement be made from a GPS antenna and still be used to accurately separate the wet and dry components of the tropospheric signal delay?
- This depends on the horizontal and vertical pressure gradient. Under conditions of hydrostatic equilibrium:

$\frac{\partial p}{\partial x}\delta x$ and $\frac{\partial p}{\partial y}\delta y$ are negligible, and

$\frac{\partial p}{\partial z}\delta z = -g\rho$ dominates.

- Even under non-hydrostatic conditions, when the horizontal pressure gradient is significant and local wind flow is high, the impact (while important) tends to be spatially localized and relatively short-lived.

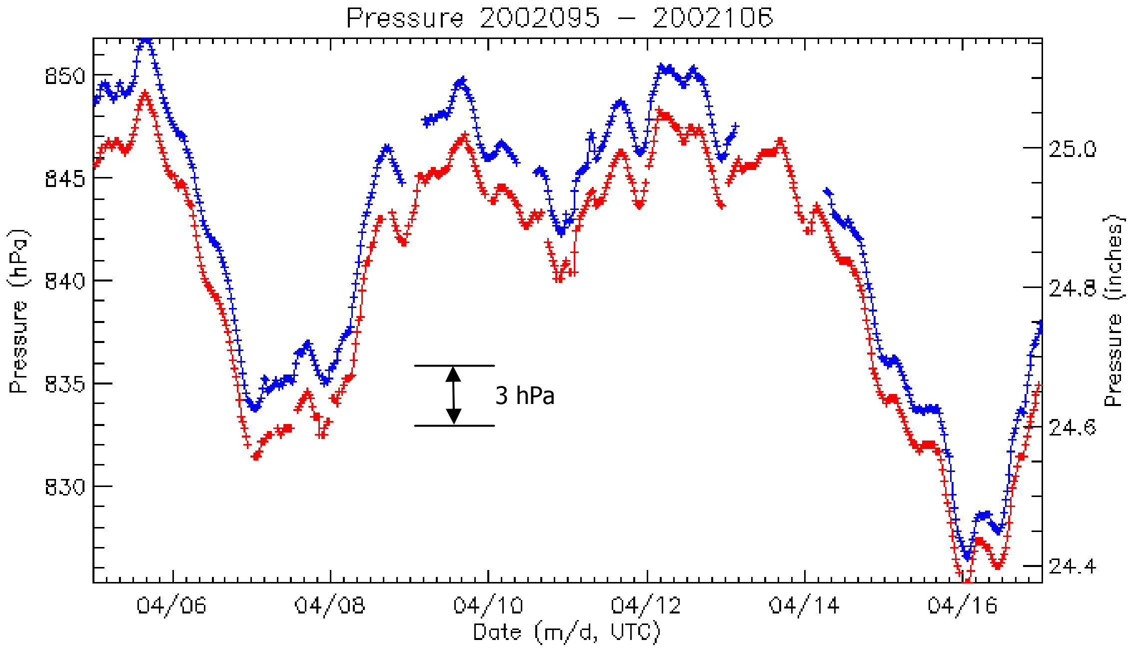
Surface Pressure at In-Fill Sites

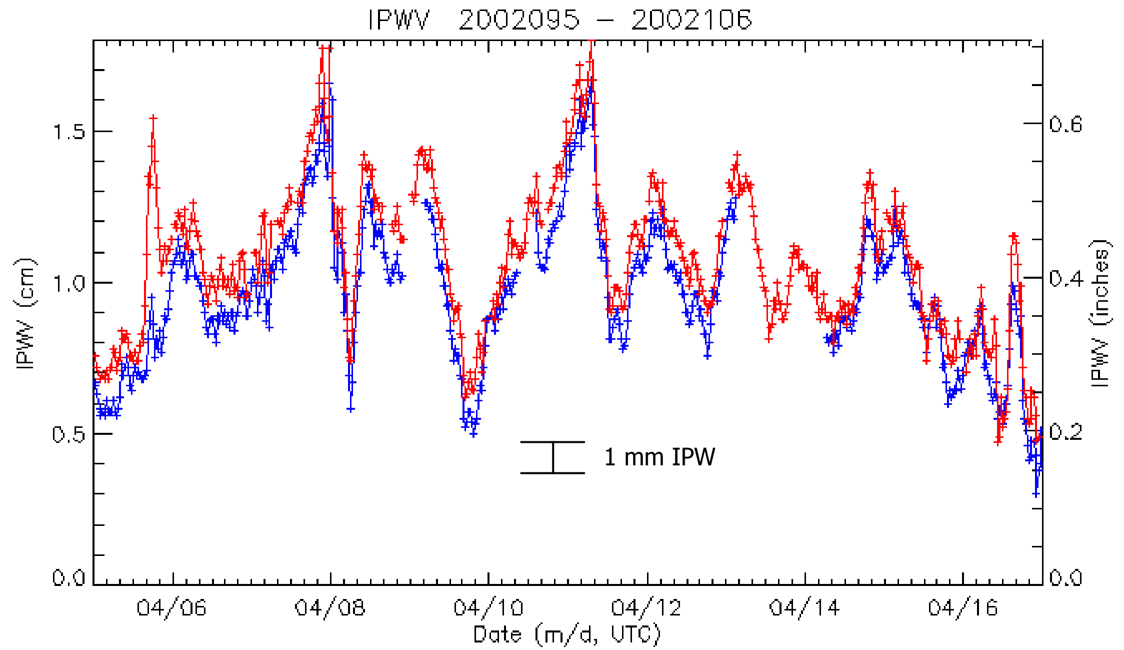
- We used data from 17 sites during the winter and 13 sites during the spring of 2001 to evaluate the impact of horizontal and vertical offsets on ***interpolated surface pressure accuracy*** under a variety of weather conditions.
- The ASOS and GSOS sites were separated by ***3 km to 53 km horizontally, and 2 meters to 200 meters vertically***. We compared GSOS surface pressure measurements (at height = *ele*) with surface pressure estimates interpolated from the altimeter setting (*Alt*) at nearby ASOS sites using the following well known formula:

$$P_{sfc} = \left[Alt^{0.193} - (1.313 \times 10^{-5}) \times ele \right]^{5.255}$$

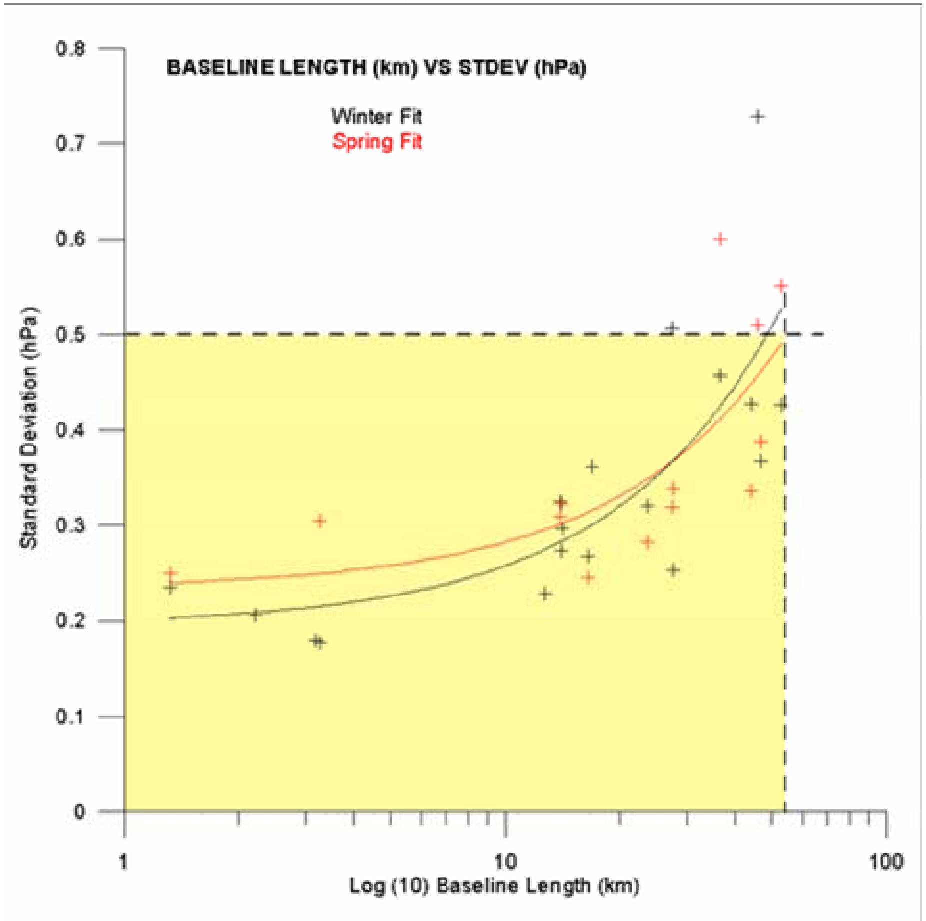
Interpolated Surface Pressure Bias

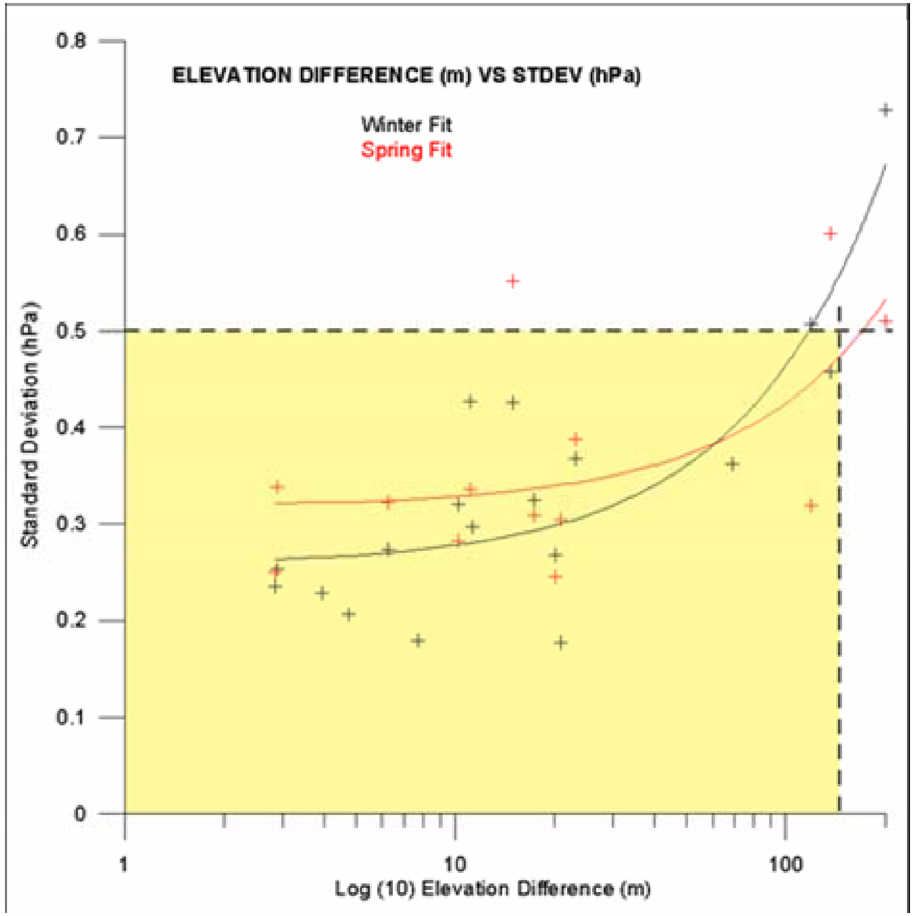
Platteville, CO Platteville , CO (ASOS at DIA)





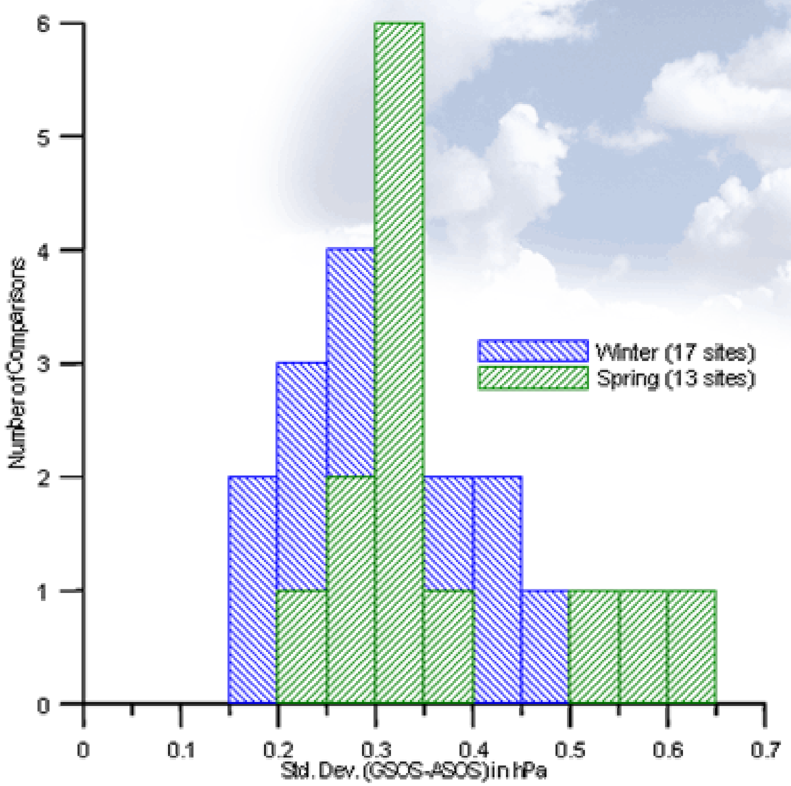
Surface Pressure at In-Fill Sites

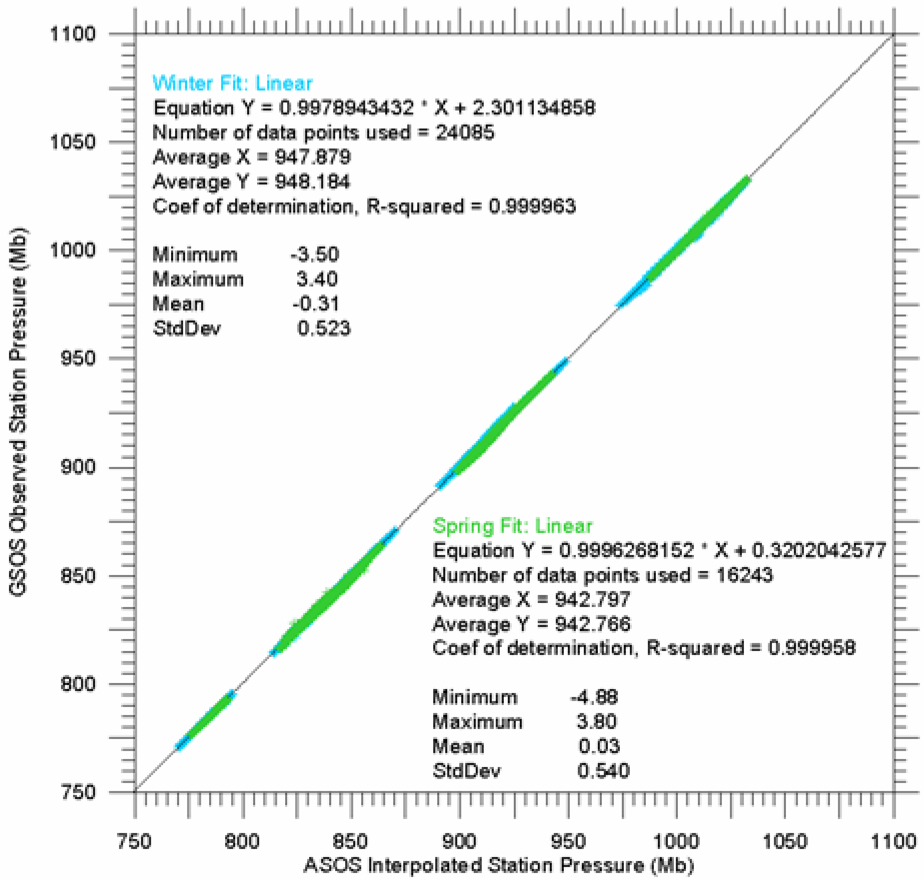




- In GPS-Met, we try to keep the pressure errors as small as possible, so that the estimated hydrostatic delay error does not dominate the IPW error budget.
- In general, a 1 hPa error in surface pressure equates to about a 0.3 mm error in IPW; well below the average minimum tropospheric delay formal error of about 0.6 mm equivalent IPW.
- This level of measurement precision is easily achieved even with old-model analog pressure sensors, but not a numerical model in any kind of terrain.

Surface Pressure at In-Fill Sites





Std. dev. of biases (GSOS-ASOS)

Reducing Interpolated Surface Pressure Biases using MSAS

- Since the surface pressure variance for GPS sites within 50 km horizontal and 100 m vertical of an ASOS site is # 0.5 hPa, we feel justified in using these remote observations. However…
- Biases appear to change seasonally, so we propose to use MSAS to define the daily bias as described in the following flowchart:

Get $ALT_{(ASOS)}$ from nearby ASOS site

↓

Upward continue (↑) $ALT_{(ASOS)}$ to elevation of GPS Antenna

↓

Find $ALT_{(GPS)}$ at GPS site from MSAS

↓

↑ $ALT_{(GPS)}$ to elevation of GPS Antenna

↓

$AB = 3(ALT_{ASOS} - ALT_{GPS})/n*24$

↓

Bias Corrected Psfc = ↑ (ALT_{ASOS}) + AB

↓

Bias Corrected Psfc to compute ZHD at GPS site without surface met sensors

Acknowledgement to Patty Miller and Mike Barth

Improving IPW Retrievals

- It was seen earlier that the GPS signal delay caused by the total amount of water vapor in the atmosphere *(ZWD)* is determined by simply subtracting the hydrostatic delay (estimated from P_{sfc}) from the tropospheric delay (measured by the GPS receiver).
- The wet delay is related to IPW through the relationship

$$IPW = \Pi \times ZWD$$

where A is a function of various physical constants and a vapor-pressure weighted "mean temperature" of the atmosphere (T_m) defined by:

$$T_m = \frac{\int \frac{P_v}{T} dz}{\int \frac{P_v}{T^2} dz}$$

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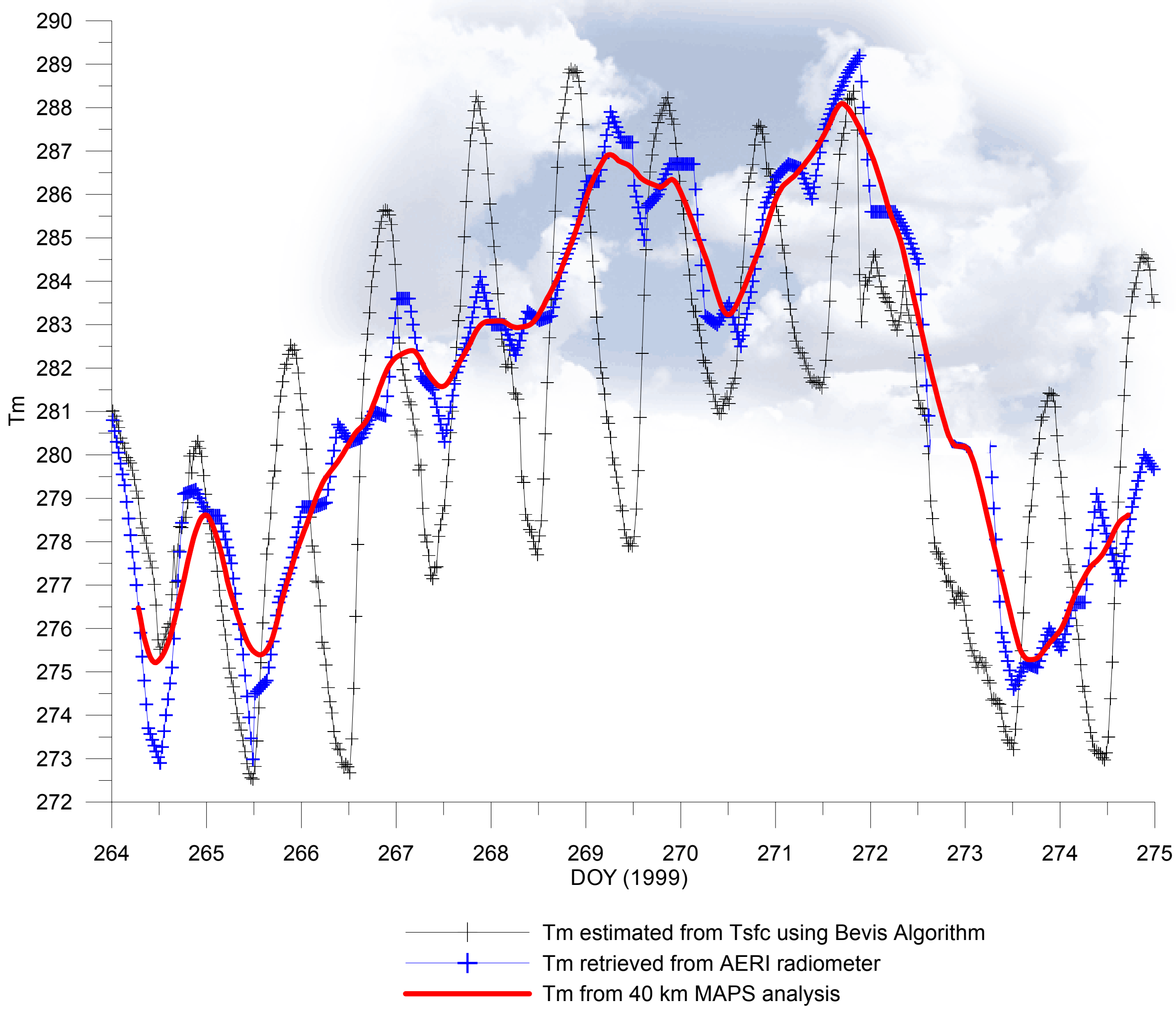
Improving IPW Retrievals

- T_m can be estimated in several ways, most commonly from a regression between tens of thousands of surface temperature measurements and raobs at upper air sites around the world (Bevis et al., 1992).
- The scatter in this regression is about 4.7° K, corresponding to a relative error of about 2% in the estimation of T_m. This introduces an average error in the IPW retrieval of 0.16 mm.
- In 1999, the branch participated in an experiment at Louisville, KY to evaluate moisture observations from the Water Vapor Sounding System (WVSS – formally CASH).
- We had an opportunity to compare T_m estimates from the Bevis algorithm with MAPS analyses and direct retrievals made by a U. Wisconsin Atmospheric Emitted Radiance Interferometer (AERI).

Improving IPW Retrievals



- The average difference between Bevis T_m estimates and AERI retrievals is about 5° K.
- Most of the scatter in the Bevis estimate of T_m comes from the diurnal variation in Tsfc that is not strongly represented in measurements or analyses.
- Differences between AERI retrieval and MAPS T_m analysis is less than 1%.
- We conclude that a model can be used to improve estimates of the wet delay mapping function.

Improving IPW by Coupling GPS-Met Retrievals to Models

Every hour:

- Process the T_m forecast values for up to 3 hours
- Replace the T_0 forecast value with the analysis value

Model data is available

Compute IPW using model T_m

Model data is not available, site has a temperature sensor

Compute IPW using temperature sensor T_m

Model data is not available, site has an ASOS site

Compute IPW using ASOS T_m

Acknowledgements: Stan Benjamin, Tracy Smith, Ara Howard

NOAA Forecast Systems Laboratory 2002 Technical Review

Selected Projects

T. Smith, S. Benjamin & B. Schwartz
FSL Forecast Research Division

S. Solomon & B. Sierk
NOAA Aeronomy Laboratory

S. Gutman
FSL Demonstration Division

May 14, 2002

Impact from high-frequency assimilation of GPS-IPW in the Rapid Update Cycle over the US

- Description of RUC
- US GPS network
- Experiments
  - 60km RUC
  - 20km RUC
- Conclusions

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Tracy Lorraine Smith
Seth Gutman
Barry Schwartz

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RUC experiments for GPS impact

- 60km RUC
  - 1998 – and still going
  - 3h cycles with and without GPS IPW assimilation
- 20km RUC
  - May 2000 – 5-day experiment
  - 1h assimilation cycles with and without GPS IPW data

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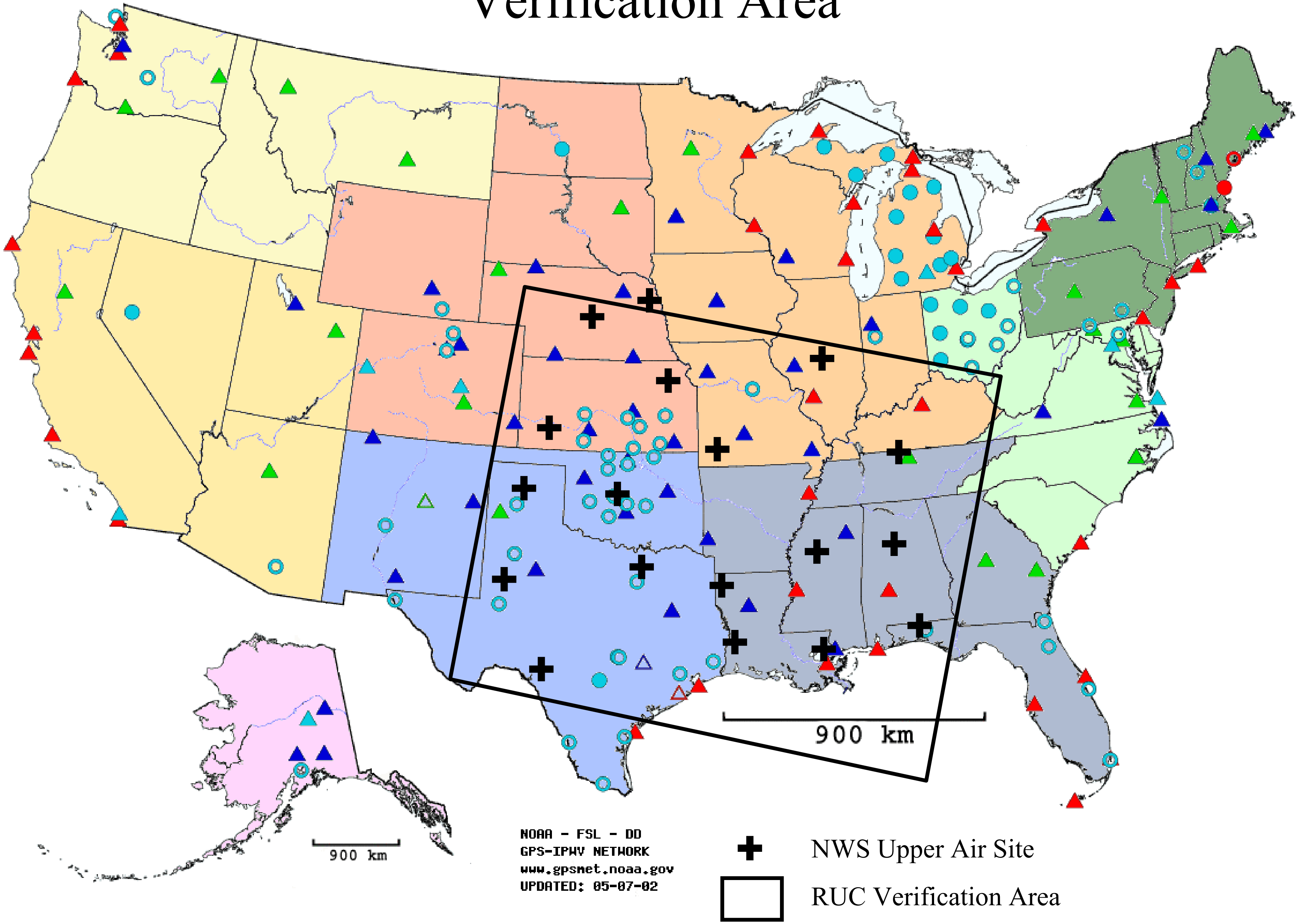
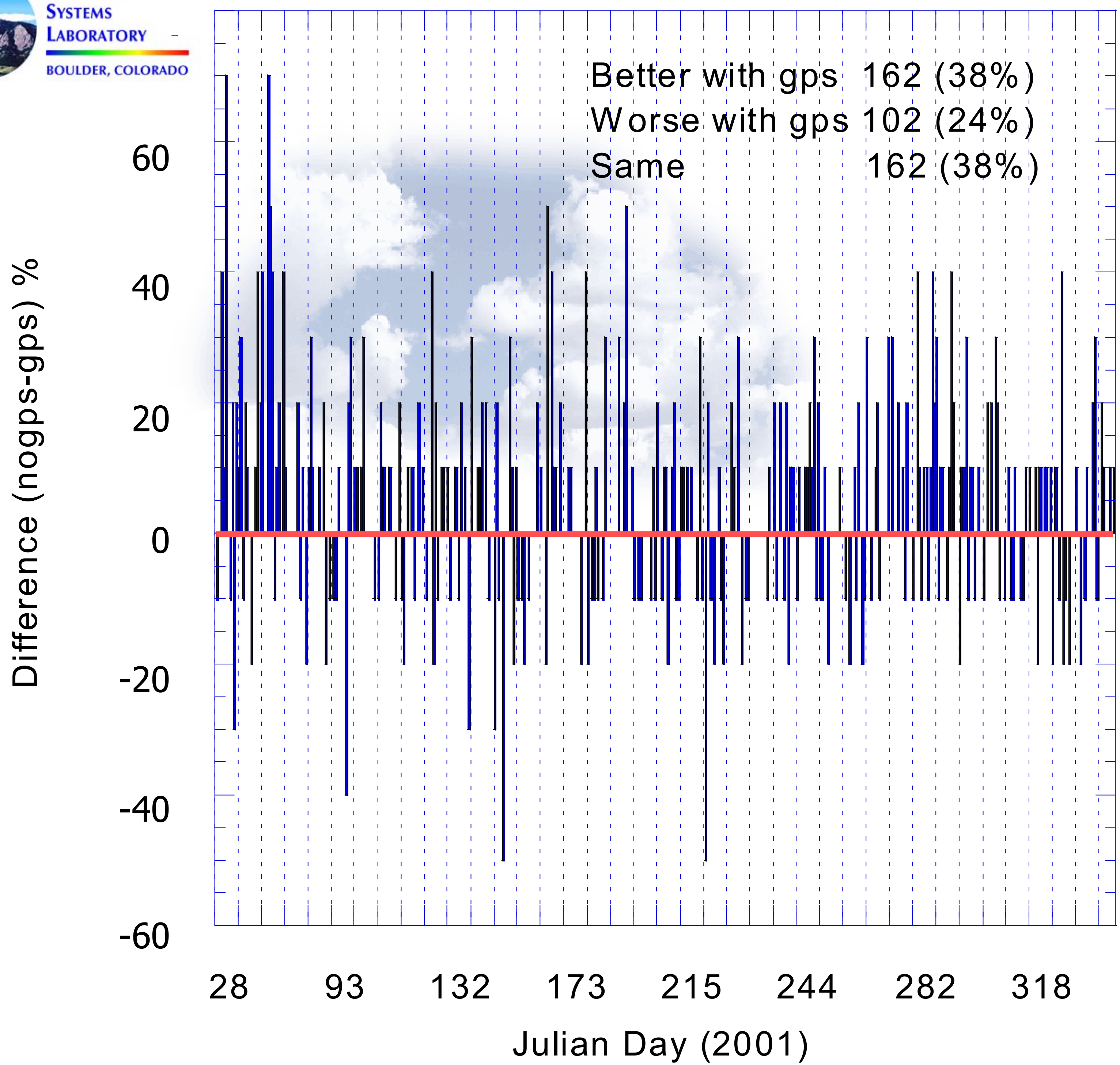
Boulder, Colorado

RUC Maps

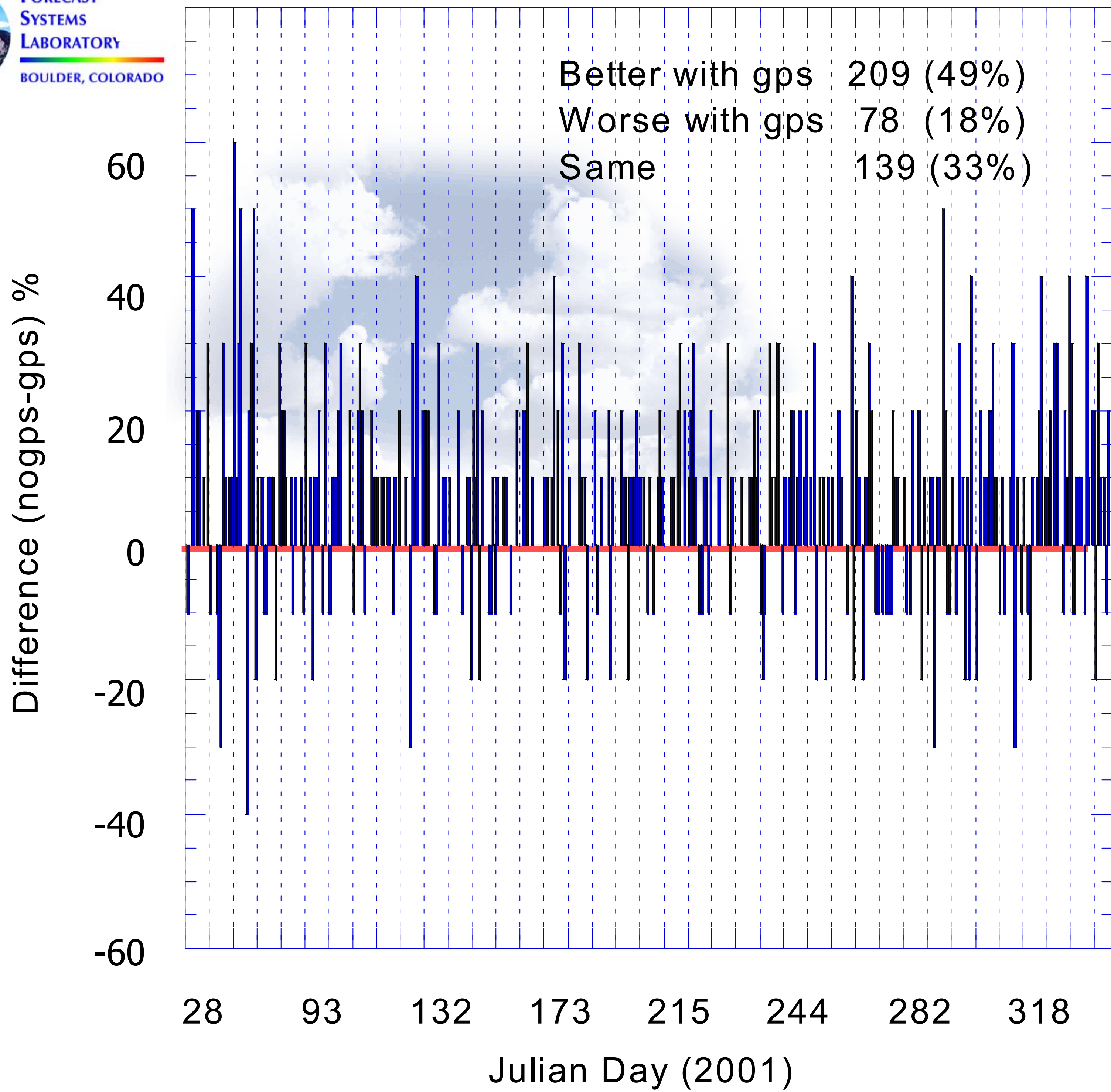
RUC Inner-Domain Verification Area





850 hPa 3h RH fcst Error (noGPS – w/GPS)

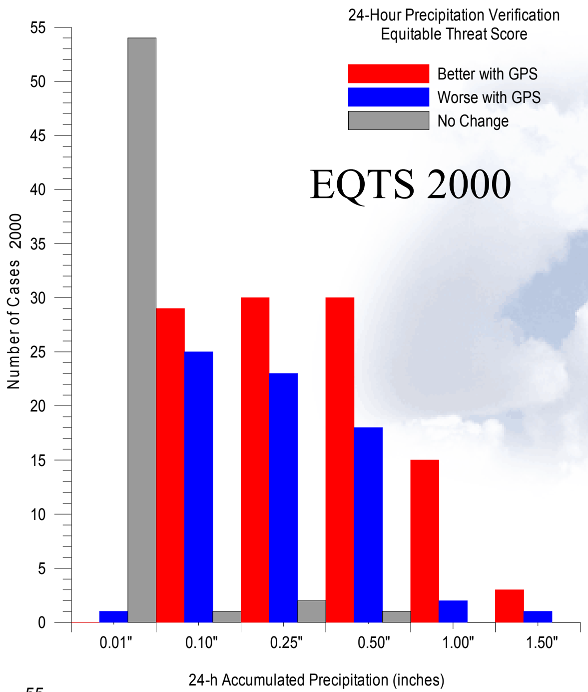
2001

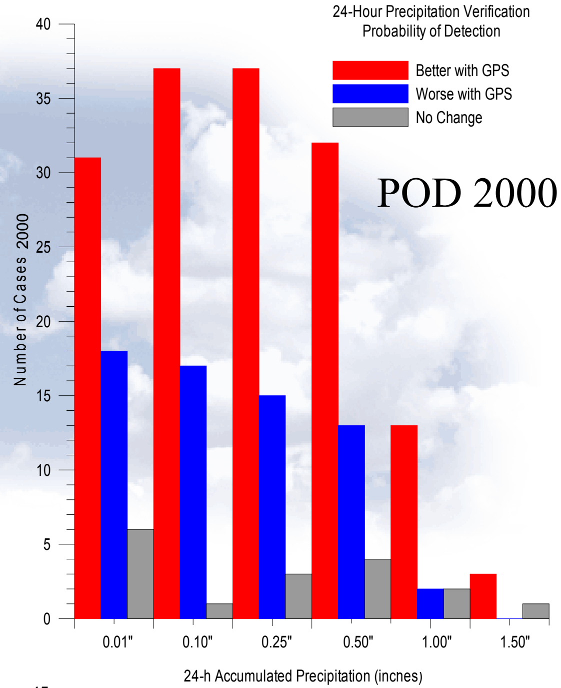


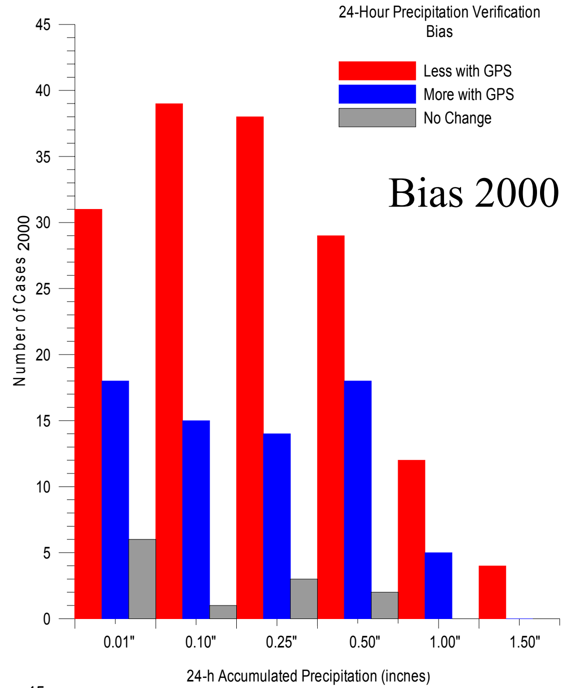
700 hPa 3h RH fcst Error (noGPS – w/GPS)

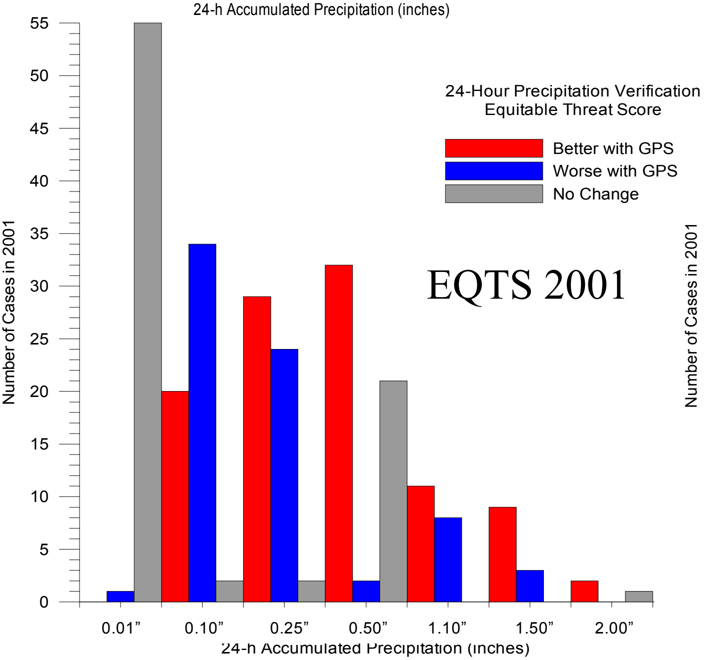
2001

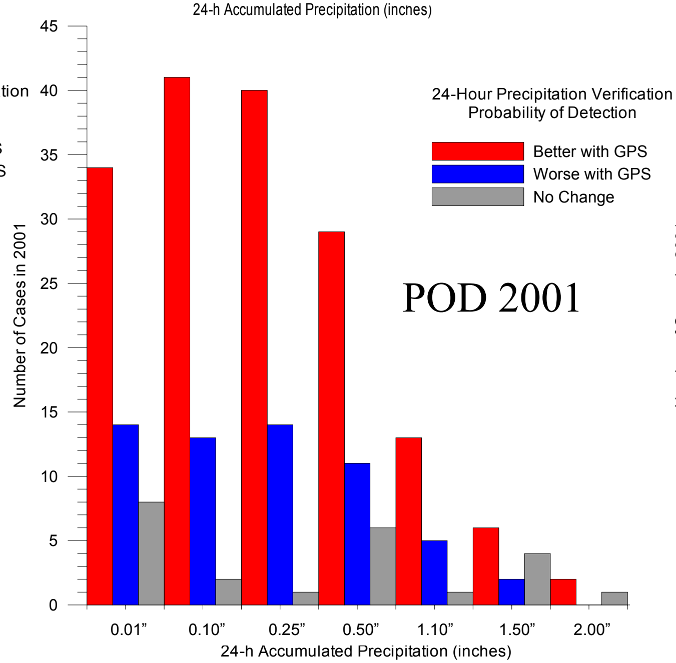
24-hour Precipitation Verification

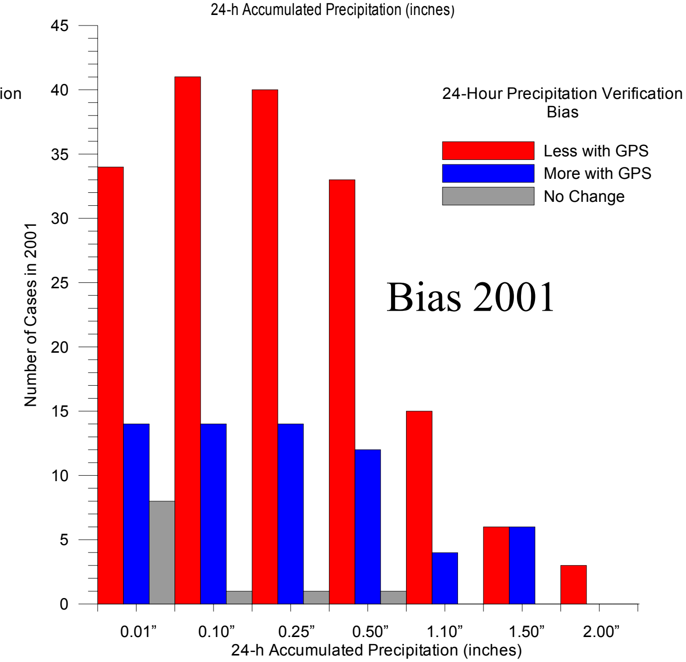




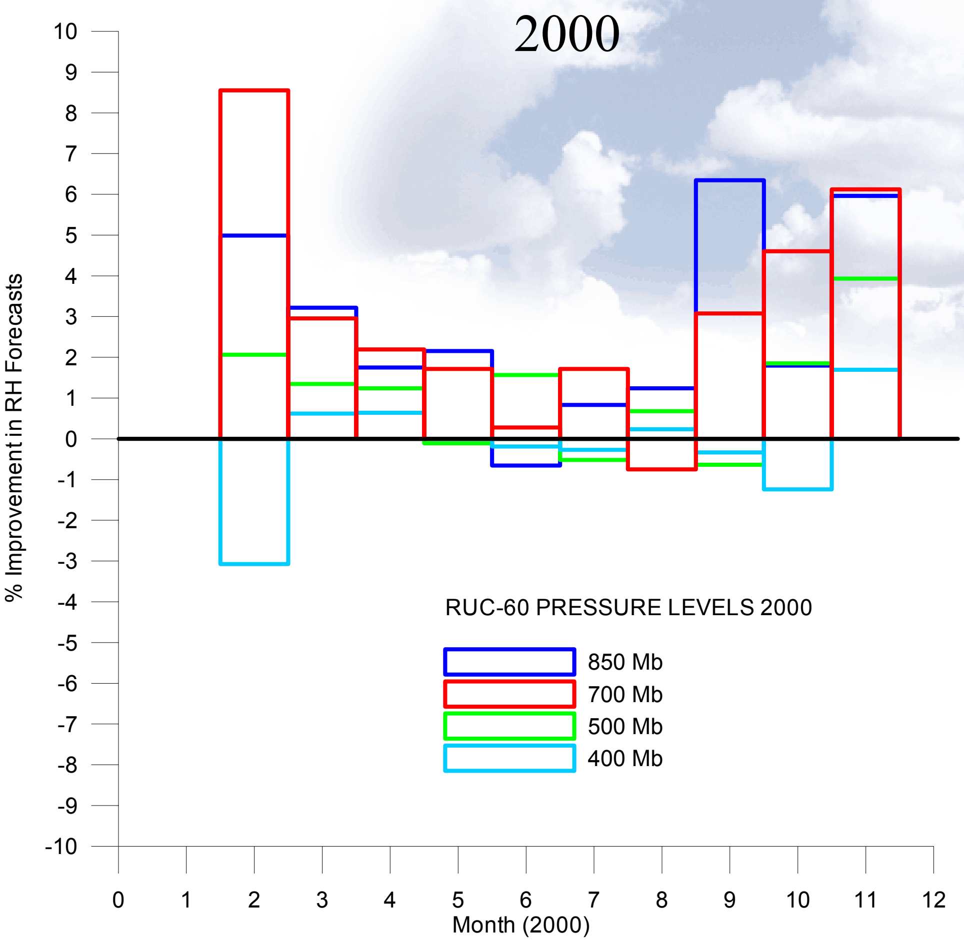




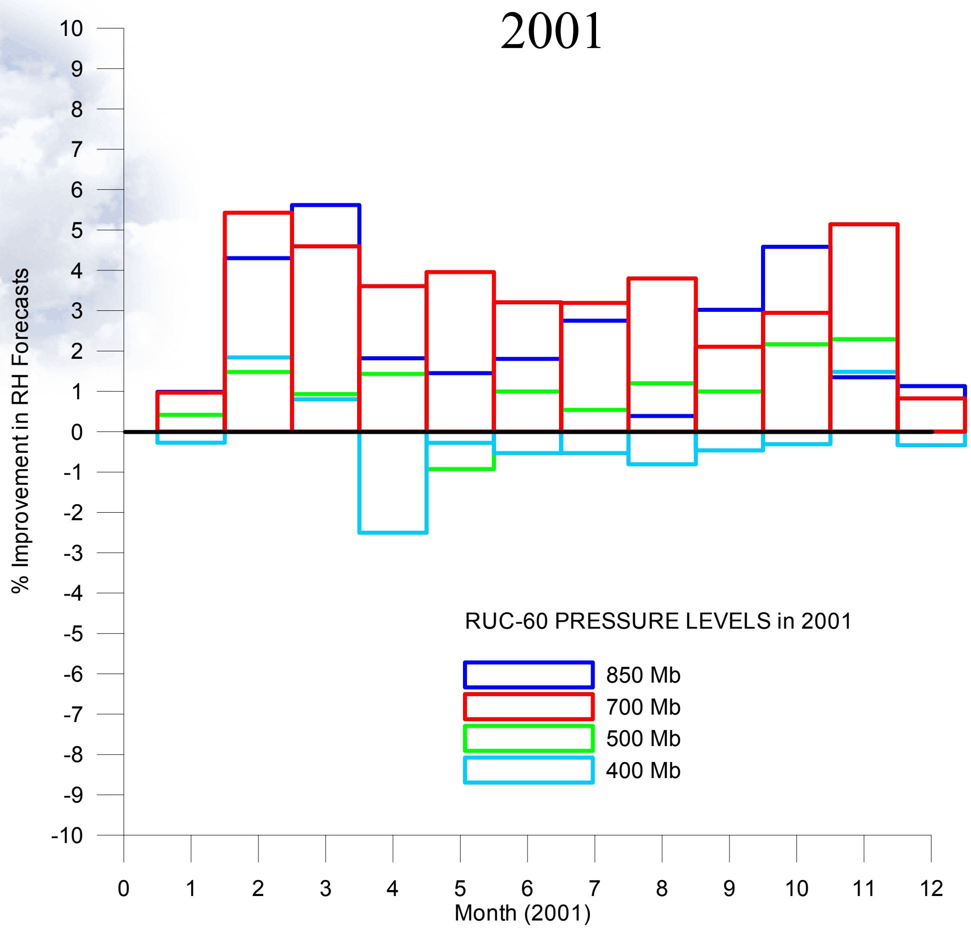




RUC60 RH 3h Forecasts - GPS Improvement by month/level – 2000/01



Percent Improvement in RH Forecast is defined as:
1-(3 h RH Forecast Error with GPS/3 h RH Forecast Error w/o GPS)*100



Percent Improvement in RH Forecast is defined as:
1-(3 h RH Forecast Error with GPS/3 h RH Forecast Error w/o GPS)*100

Conclusions – RUC60 GPS impact tests

- Multi-year study with the 60km RUC indicates that GPS-Met makes a small but consistent positive impact on short-term weather forecast accuracy:
  - primarily at the lower levels where most of the moisture resides - IPW more correlated w/ *low*-level moisture
  - magnitude of impact consistently increases with the number of stations
  - impact on precipitation forecast accuracy generally increases with precip amount threshold
  - RH forecast accuracy is greatest in the cool months when convection is less frequent and the moisture distribution is correspondingly less spotty.

No. Sta	18	56	67	100+
Level	1998-99	2000	2001	2002
	% improvement (normalized by total error)			
850	1.5	3.8	3.9	7.2
700	1.1	4.1	6.3	6.6
500	0.7	2.1	2.0	0.0
400	0.3	0.1	-0.4	-1.9
Mean	0.9	2.5	2.9	3.0

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Data for 20-km RUC at NCEP

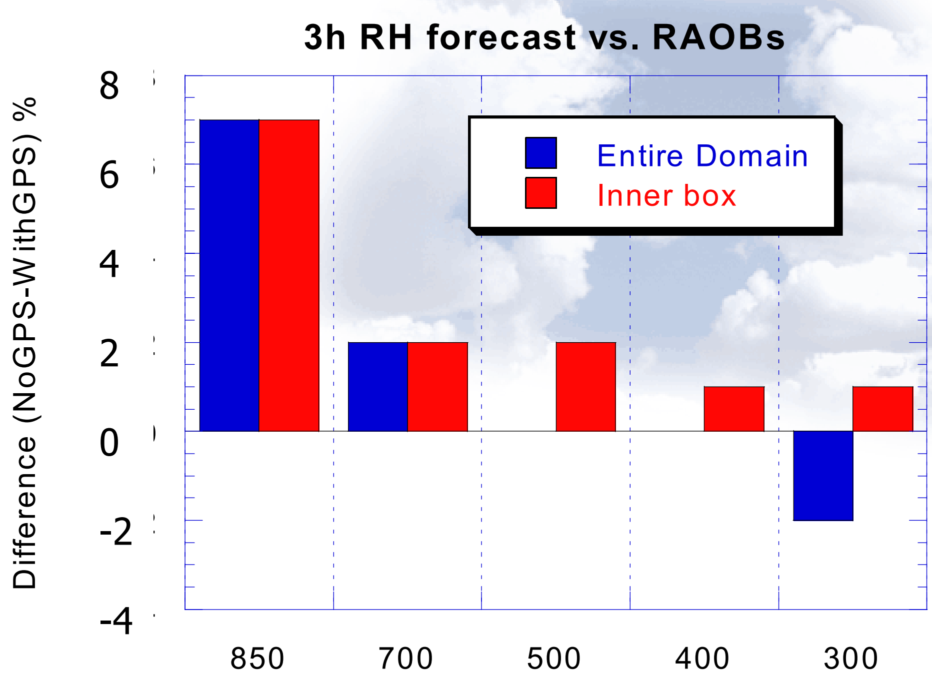
RUC MAPS

Data Type	~Number	Freq.
Rawinsonde (inc. special obs)	80	/12h
NOAA 404 MHz profilers	31	/ 1h
Boundary-layer (915 MHz) profilers *	~24	/ 1h
VAD winds (WSR-88D radars)	110-130	/ 1h
Aircraft (ACARS) (V,temp)	1400-4500	/ 1h
Surface/METAR - land (V, p_{sfc}, T, T_d)	1500-1700	/ 1h
Buoy	100-150	/ 1h
GOES precipitable water	1500-3000	/ 1h
GOES cloud drift winds	1000-2500	/ 1h
GOES cloud-top pressure *	~10km res	/ 1h
SSM/I precipitable water	1000-4000	/ 6h
GPS precipitable water *	100+	/ 1h
Ship reports	10s	/ 3h
Reconnaissance dropwinsonde	a few	/ variable

* New for 20km RUC at NCEP

Availability pending

RUC20 parallel tests - 23-28 May 2000



3h RH forecast error diff - ΔError (noGPS-GPS)

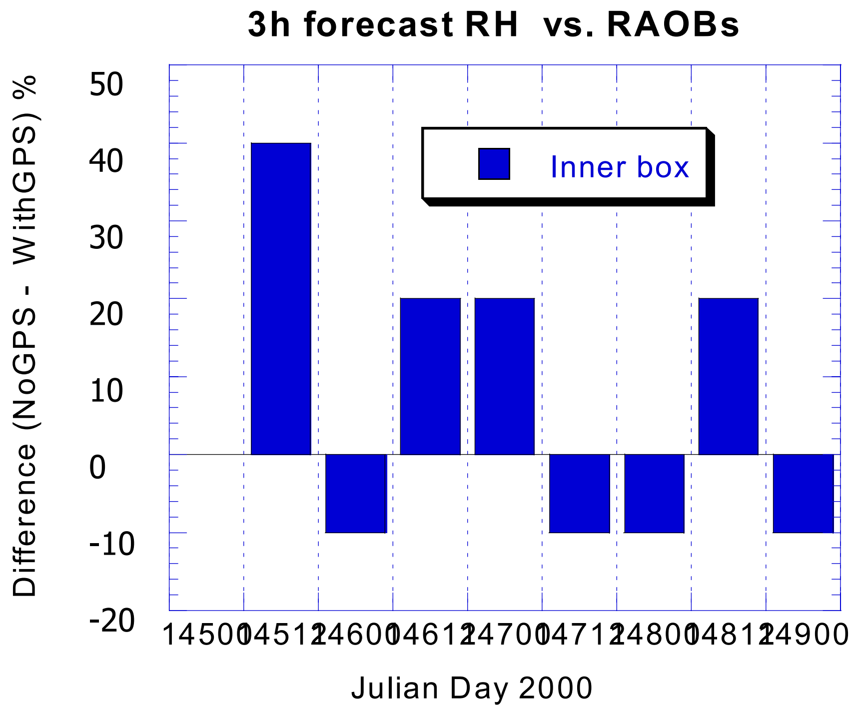
Error (GPS – model only)

Average by level

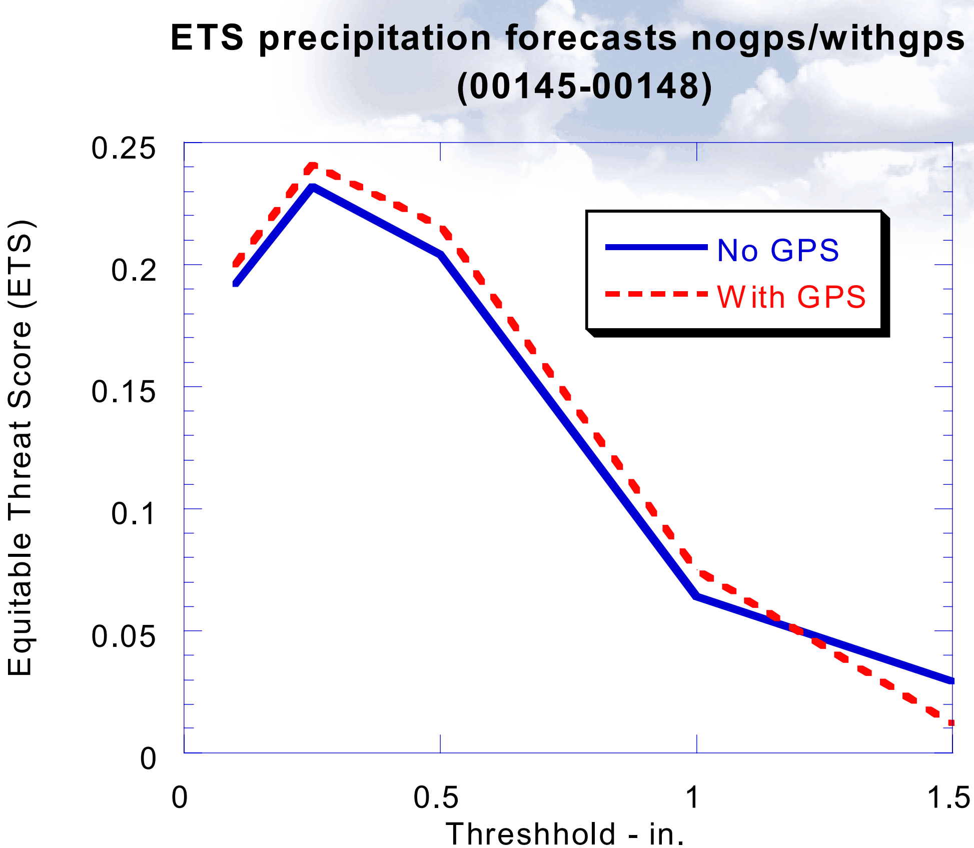
Mean values (850-500)

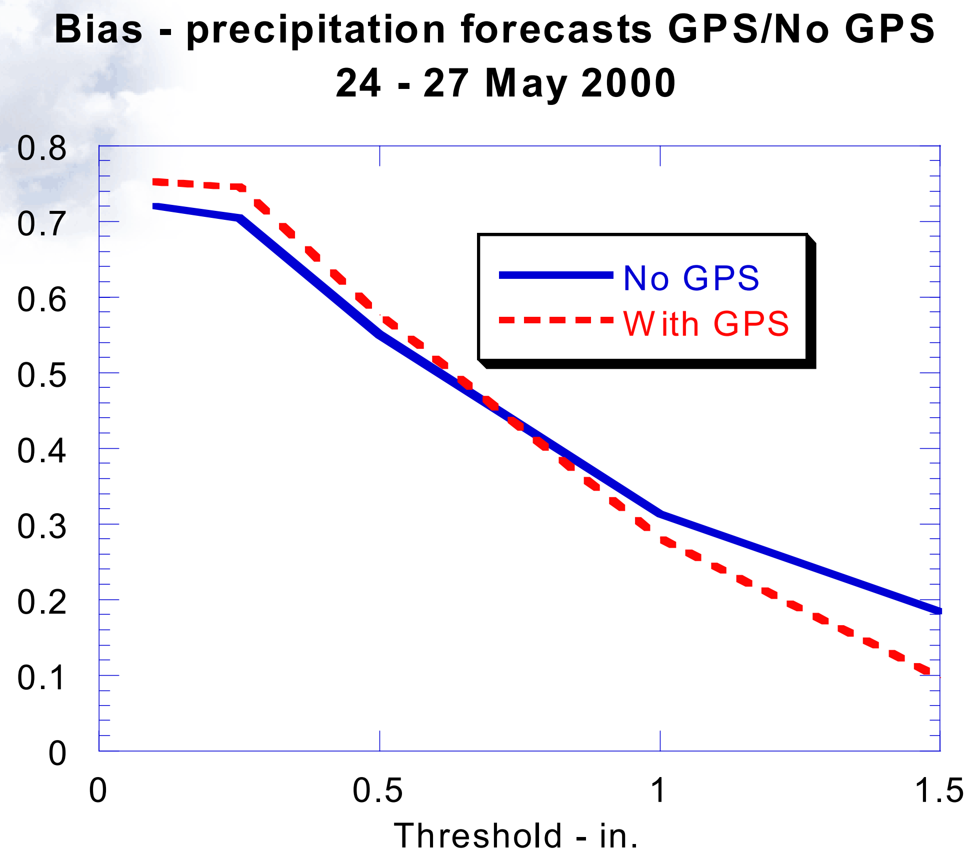
Inner box	3.7
Entire domain	3.0

850 hPa time-by-time



RUC20 precipitation forecasts 24h total from sum of two 12h forecasts with and without GPS





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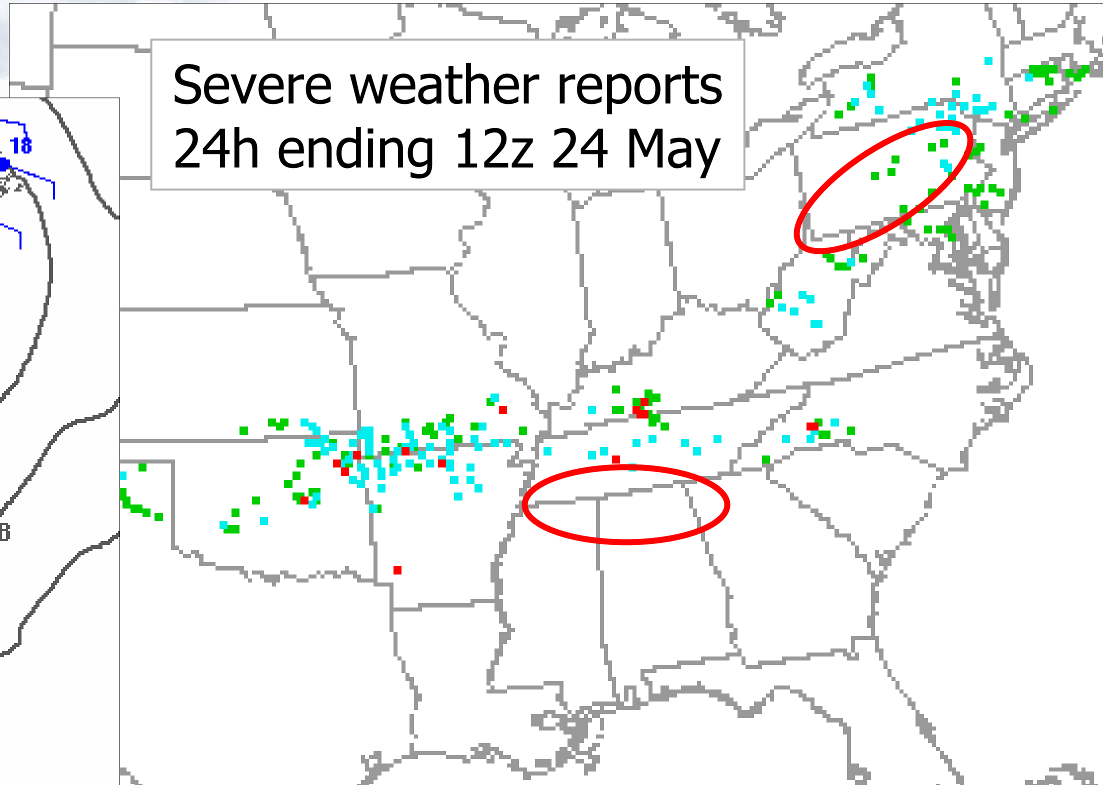
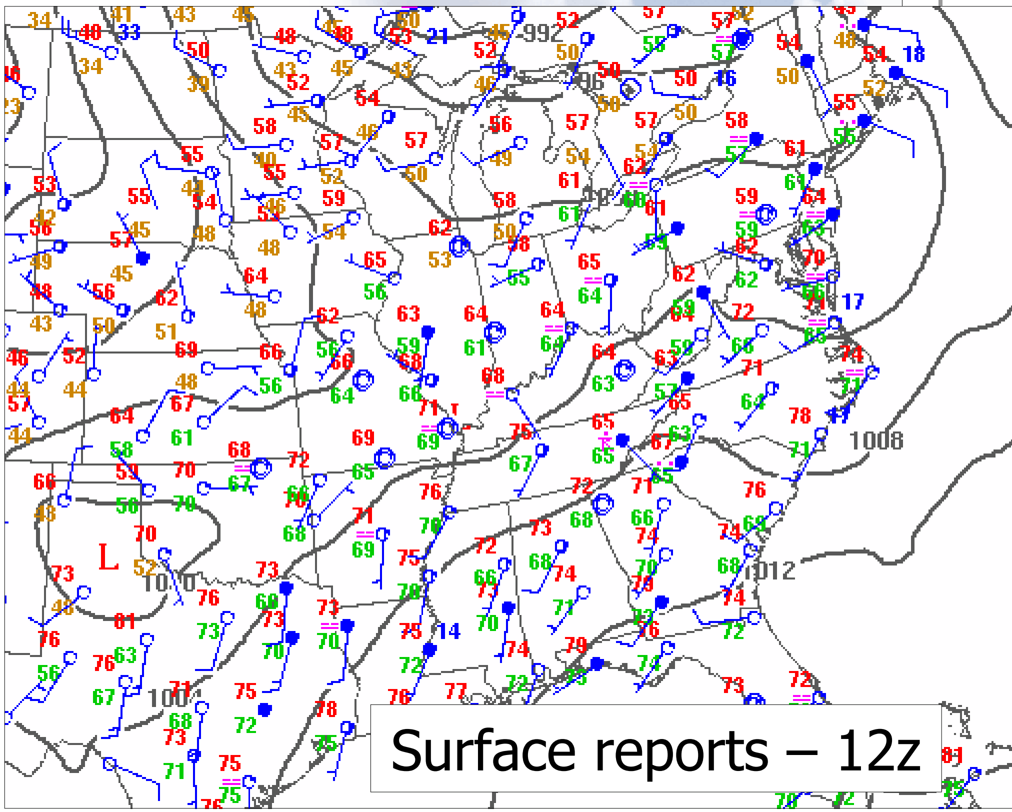
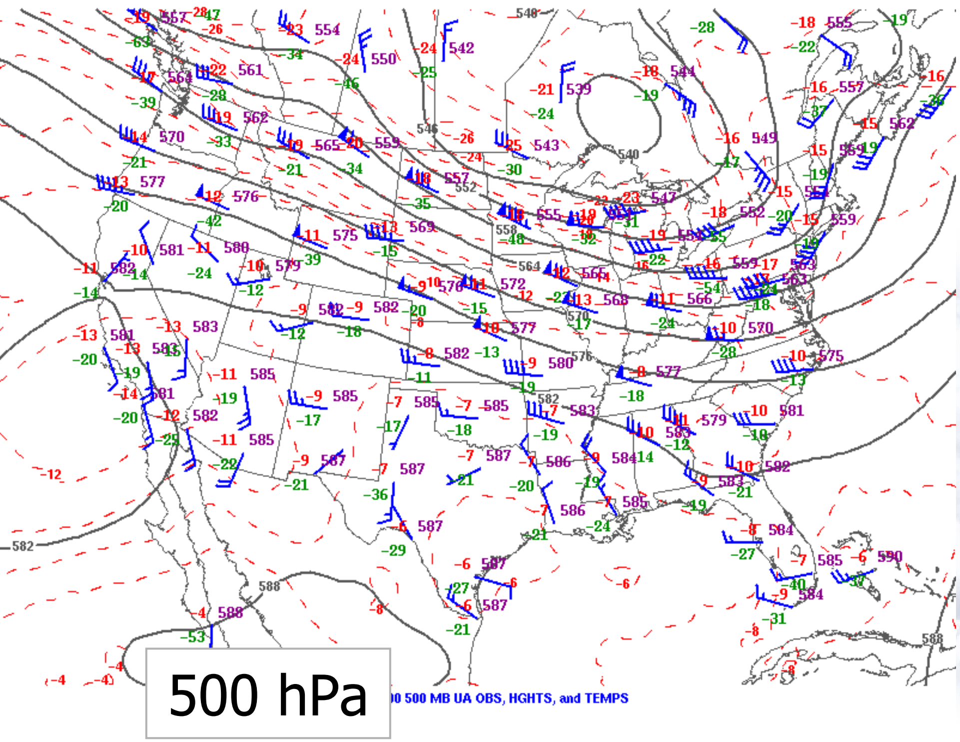
Case study for GPS impact using 20km RUC

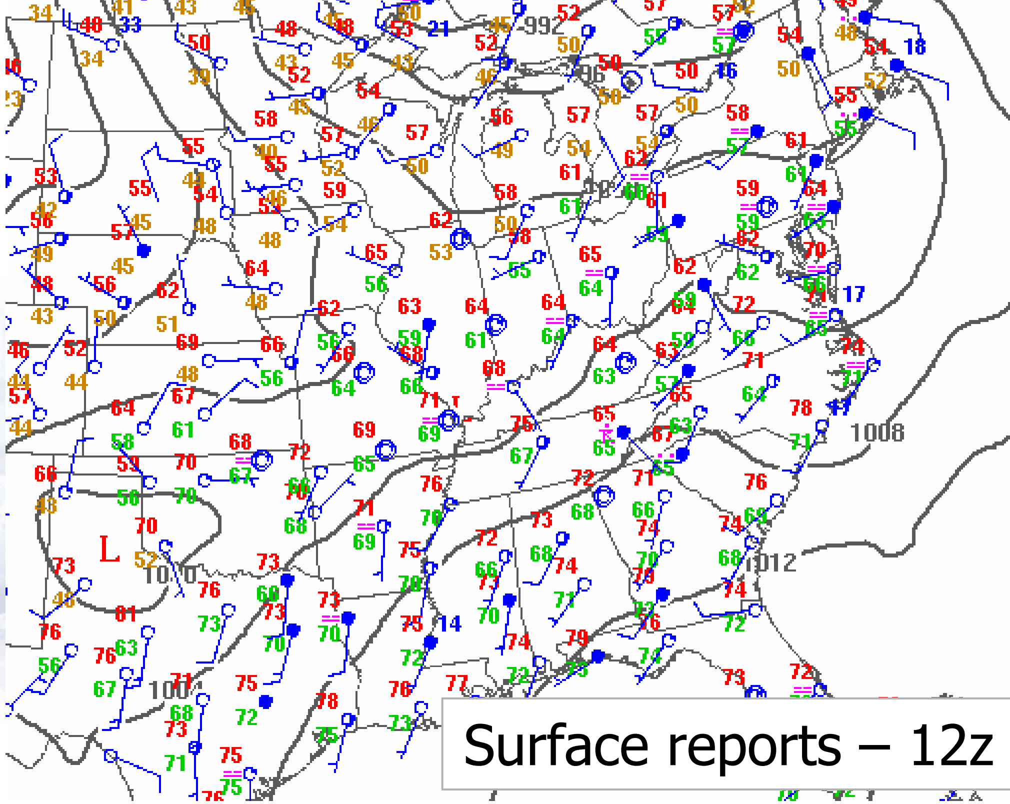
RUC MAPS

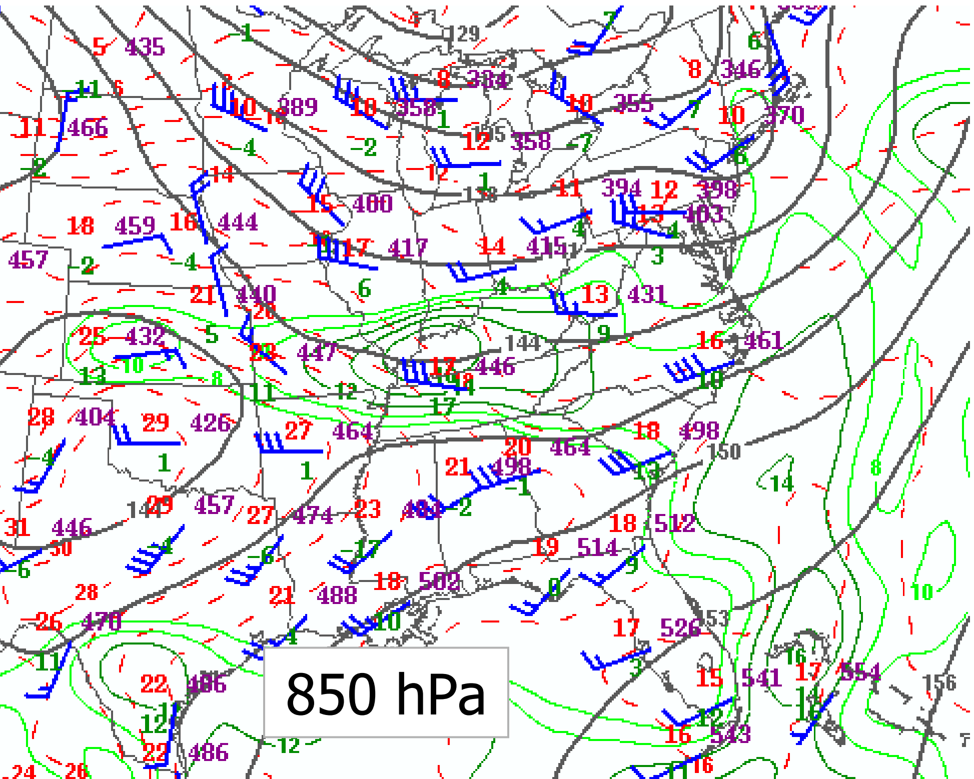
0000-1200 UTC
24 May 1200

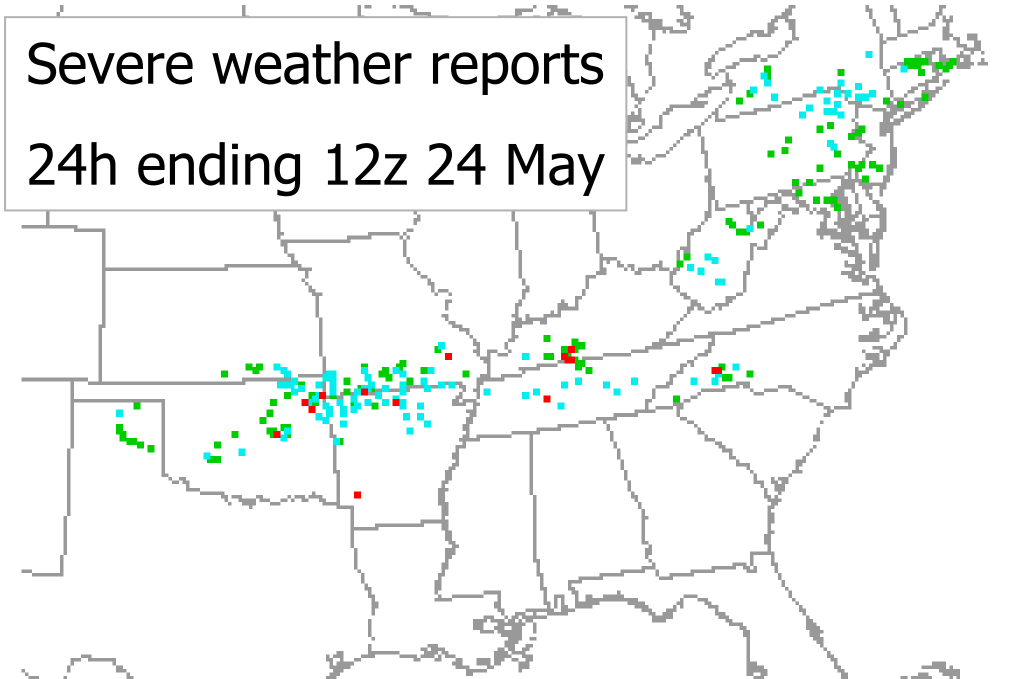




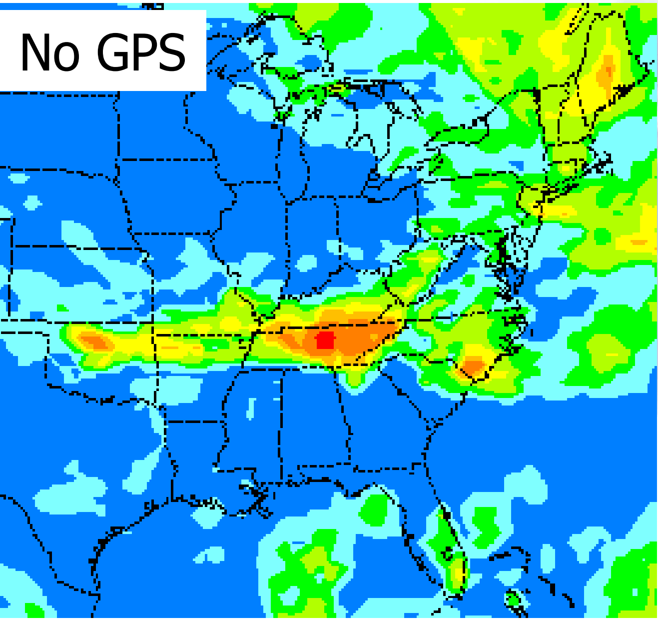

500 hPa
500 MB UA OBS, HGHTS, and TEMPS

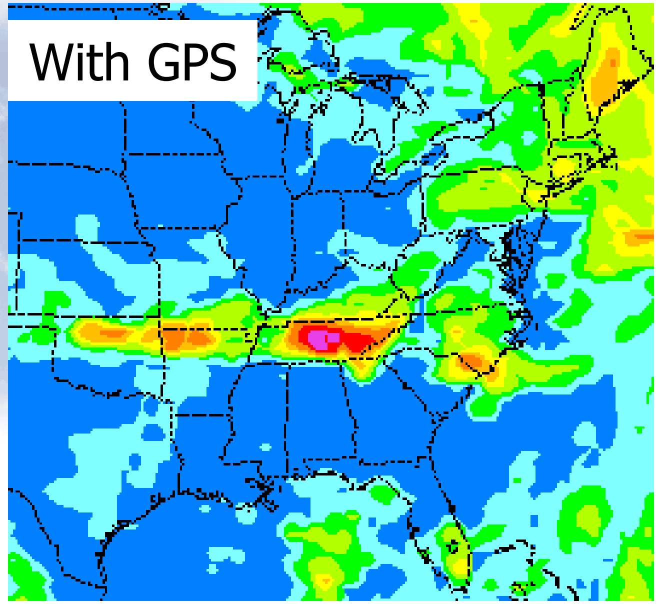

Surface reports – 12z

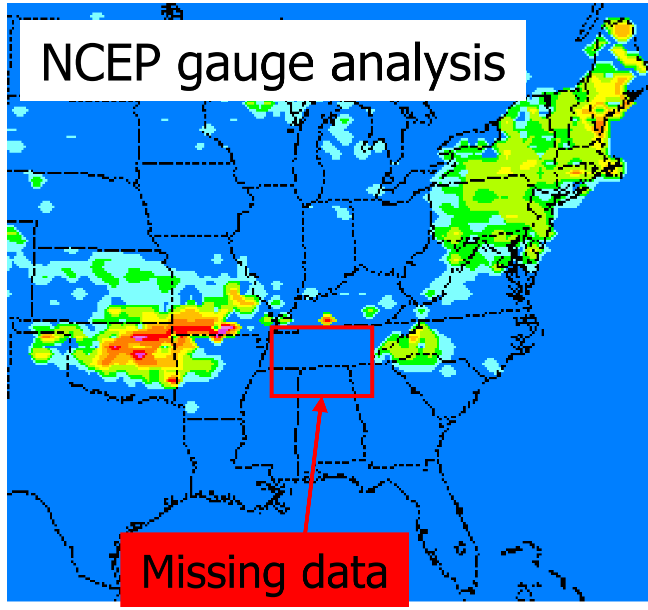

850 hPa


Severe weather reports
24h ending 12z 24 May

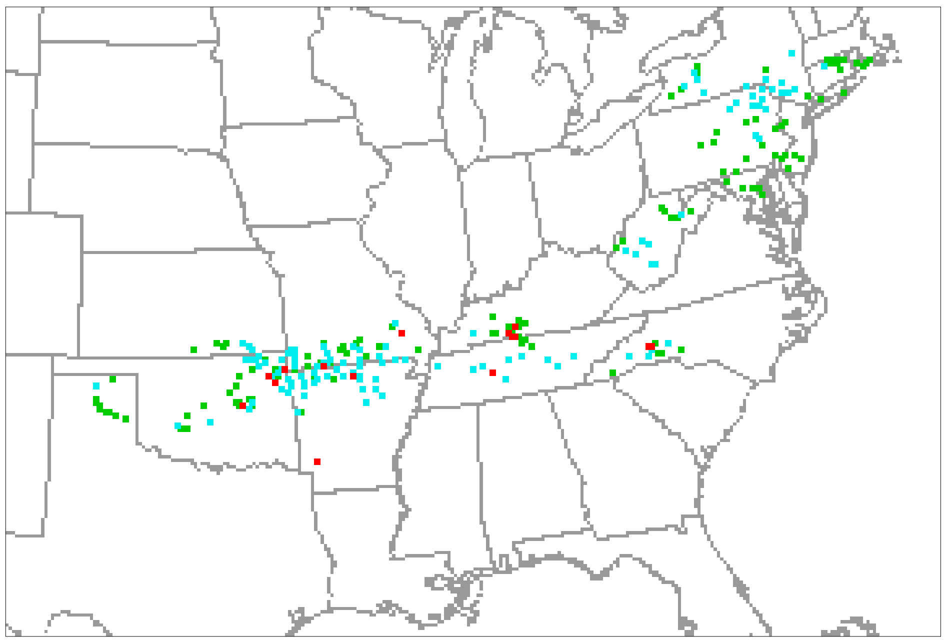
RUC20 24h precipitation forecasts – end 12z 24 May 00

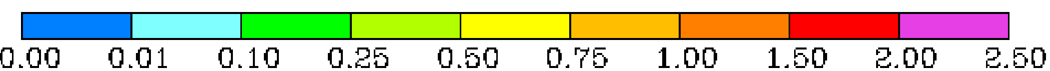




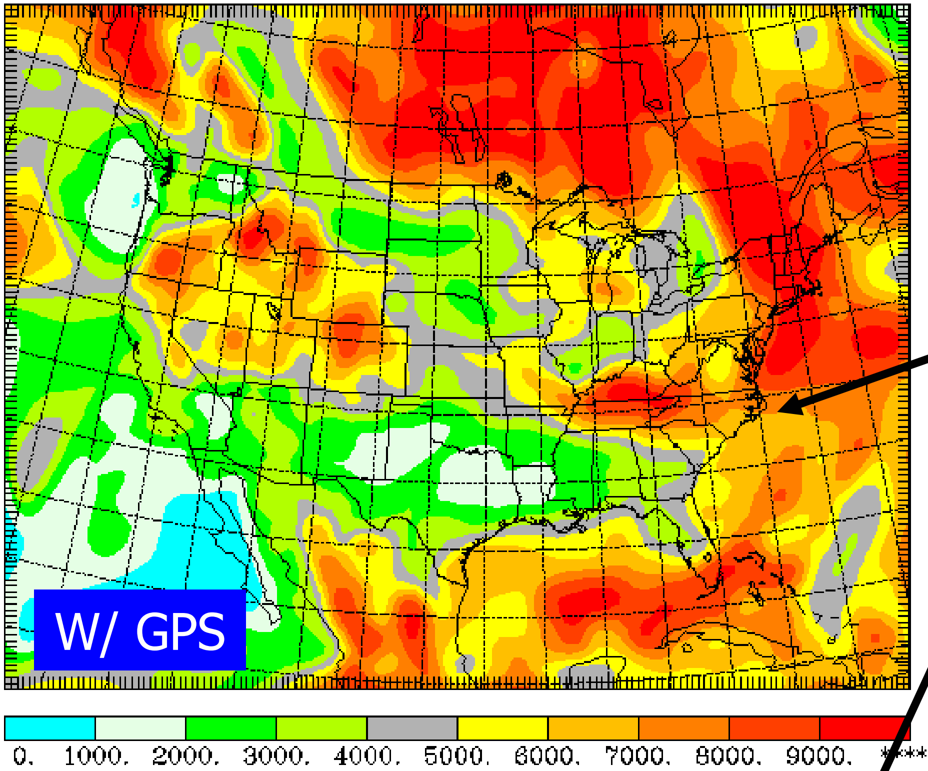


Severe weather =
- Hail > 2 cm
- Wind> 30 m/s
- Tornado



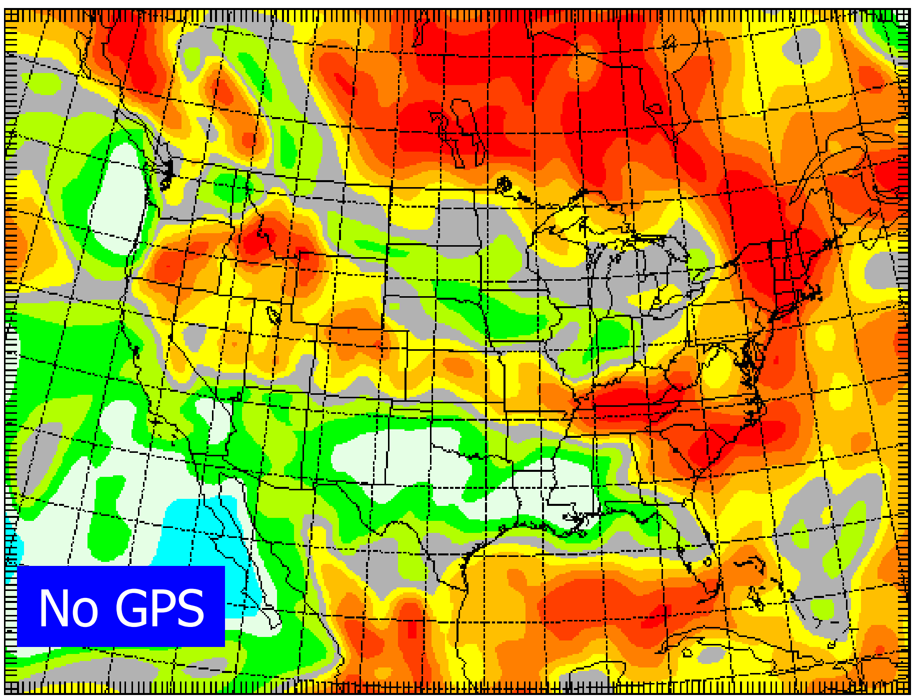


850hPa RH forecast
-3h fcst valid 12z 24May00

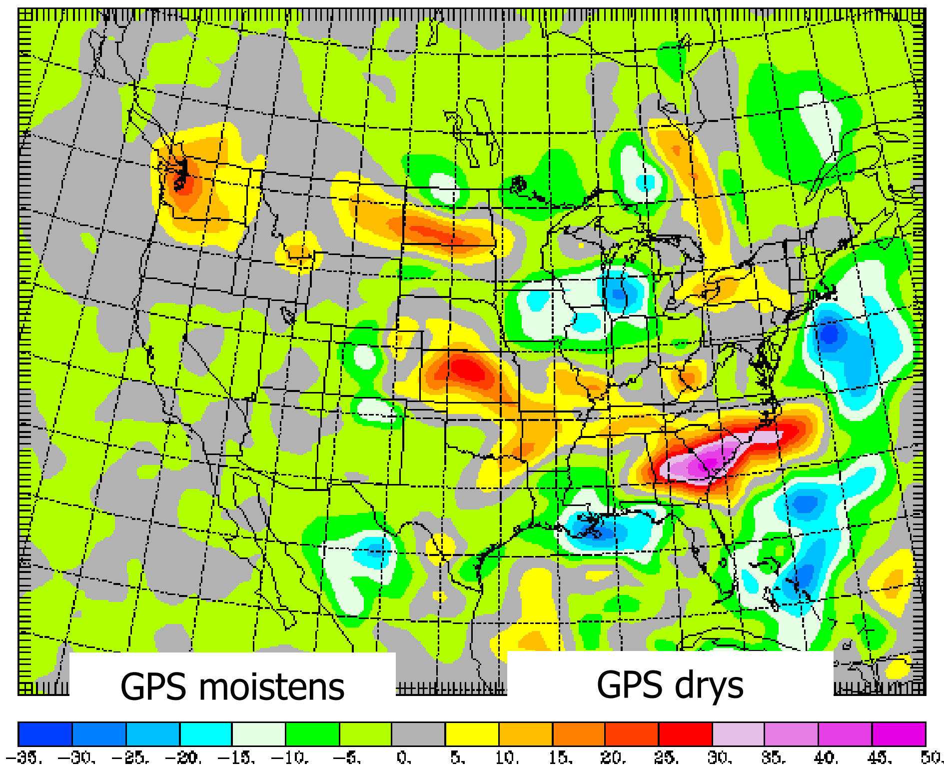


With GPS

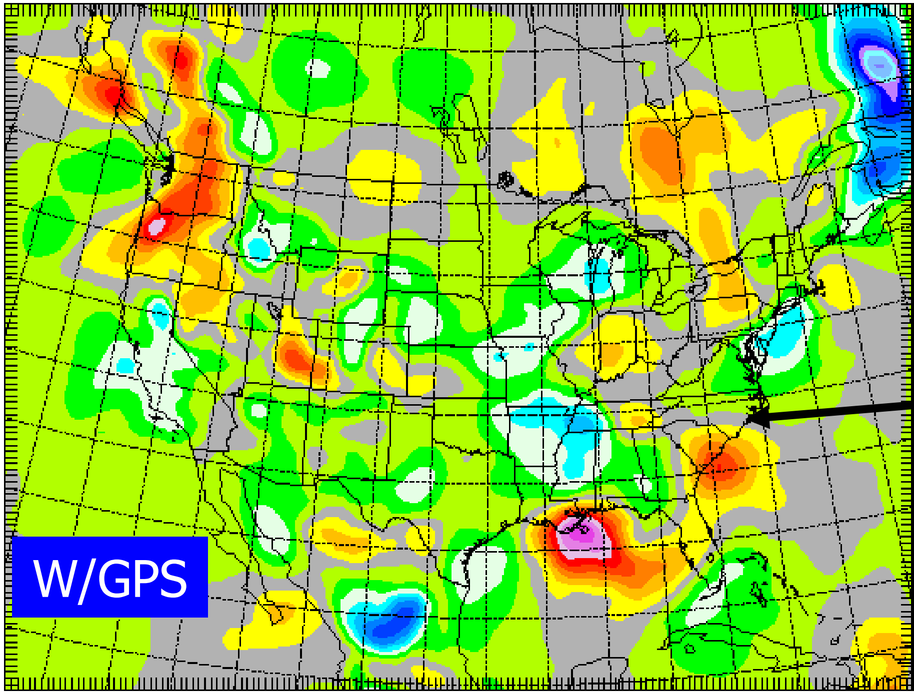
Without GPS



Difference in 850 hPa RH 3h fcsts
No-GPS minus w/GPS

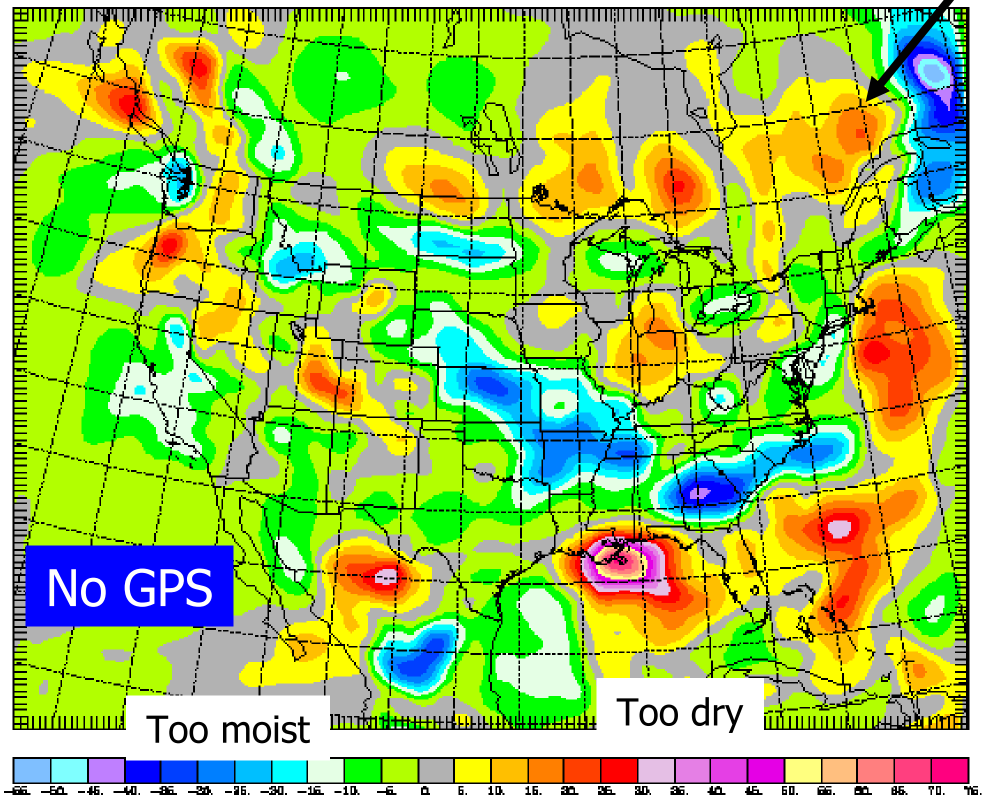


850hPa RH forecast **error**
-3h fcst valid 12z 24May00

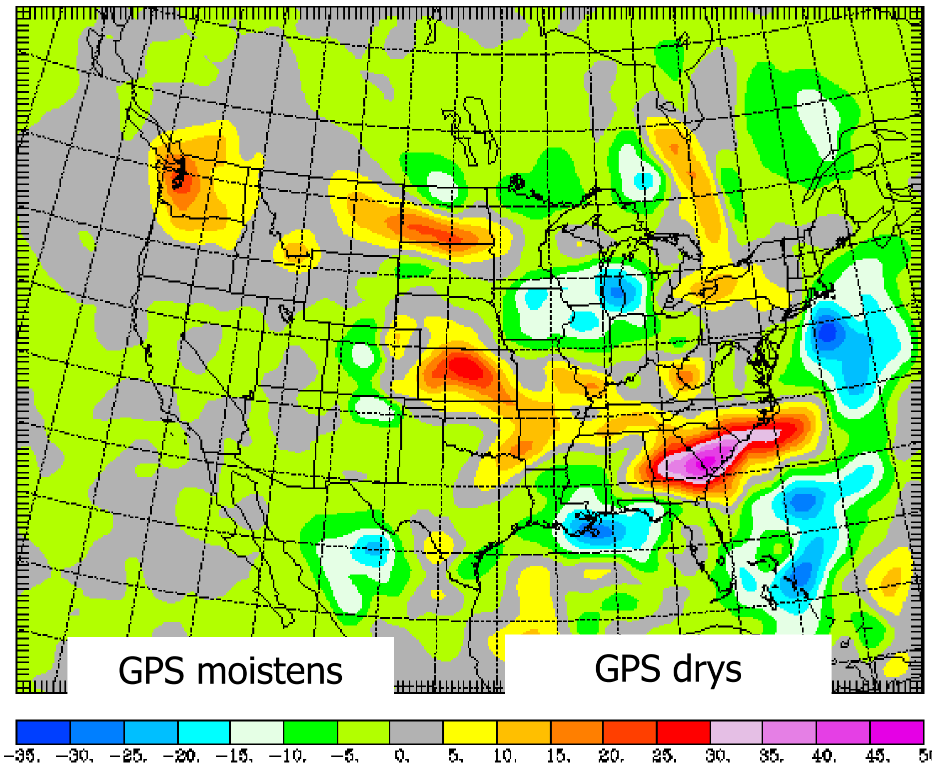


With GPS

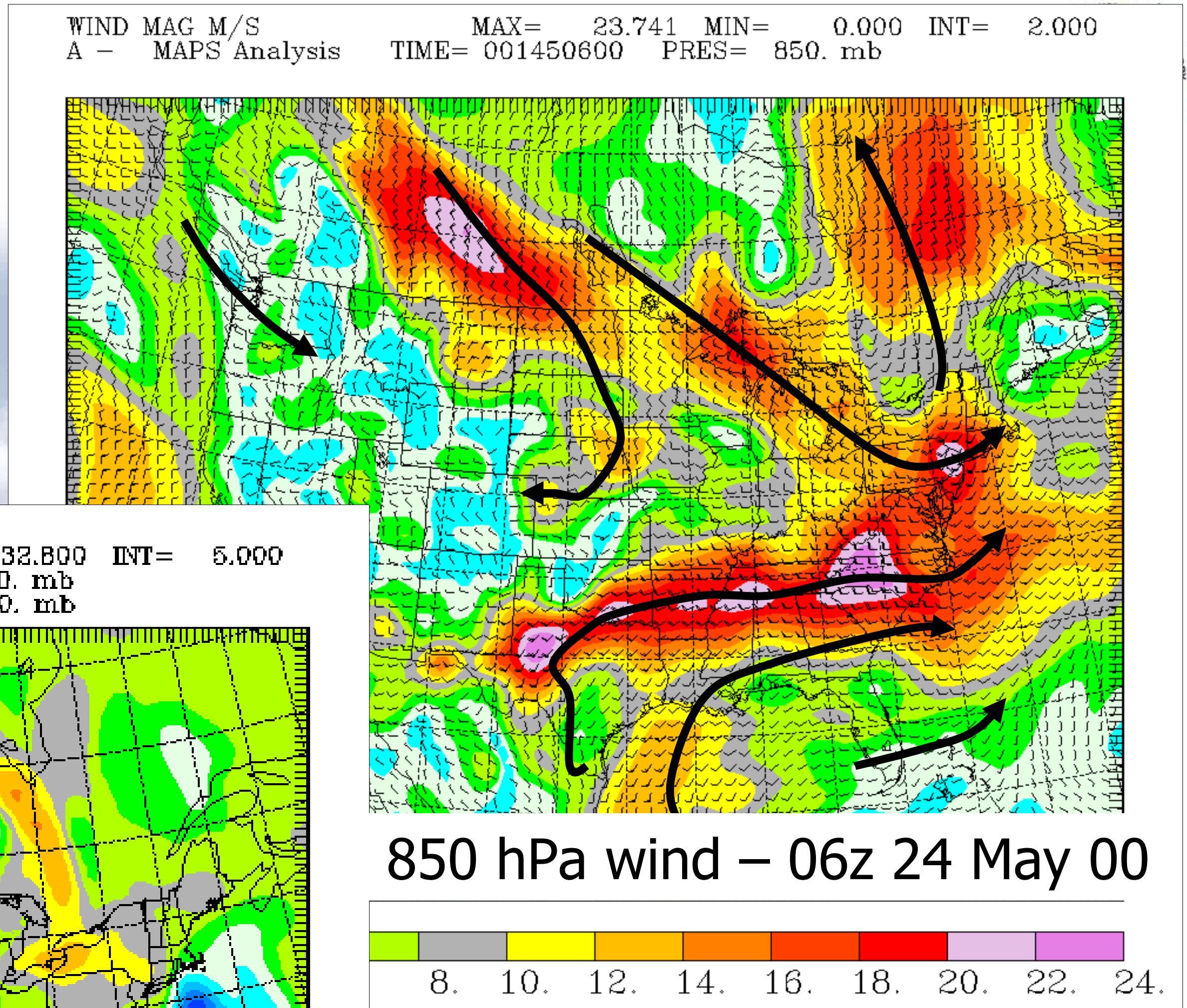
Without GPS



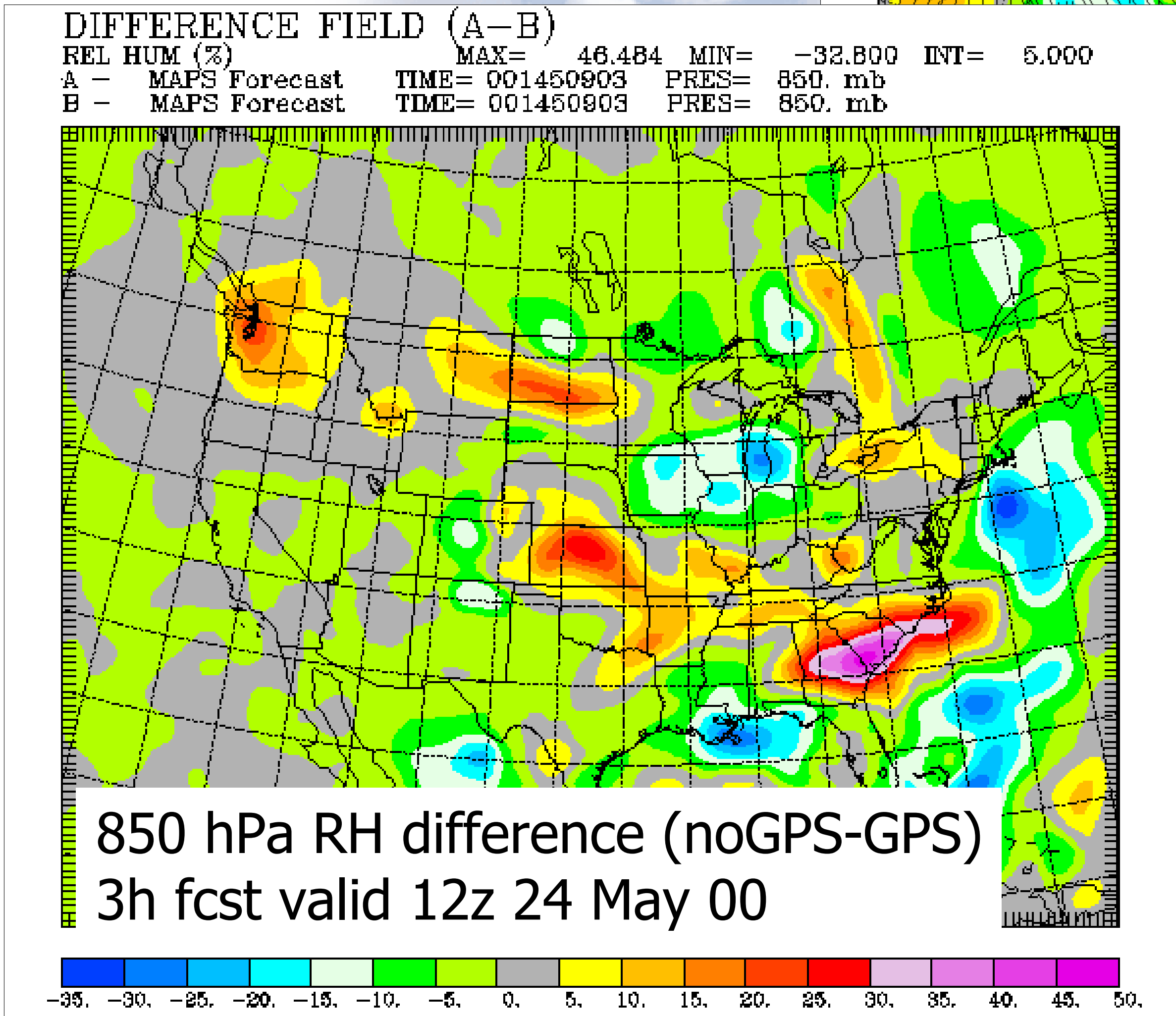
Difference in 850 hPa RH 3h fcsts
W/GPS minus no-GPS



Plumes of GPS influence from hourly assimilation cycle in RUC



850 hPa wind – 06z 24 May 00



850 hPa RH difference (noGPS-GPS)
3h fcst valid 12z 24 May 00

Modifications to meso-alpha-scale (100-400 km) moisture field

Conclusions from RUC20 GPS impact tests

- Test for only 5 days, but with much improved model and data assimilation
- Impact on 3h RH forecast similar to that from RUC60
- Impact on precipitation positive and stronger than with RUC60 tests
- Case study shows mesoscale plumes from 1h cycle assimilation of GPS data,
  drying in regions of heavier precipitation

Future

Multi-week RUC20 impact tests – May 2000, Feb 2001

Assimilation into operational RUC20 at NCEP

GPS meteorology as a tool in the study of radiative transfer

Bernard Sierk and Susan Solomon

NOAA Aeronomy Laboratory
Advancing Our Understanding of the Earth's Atmosphere

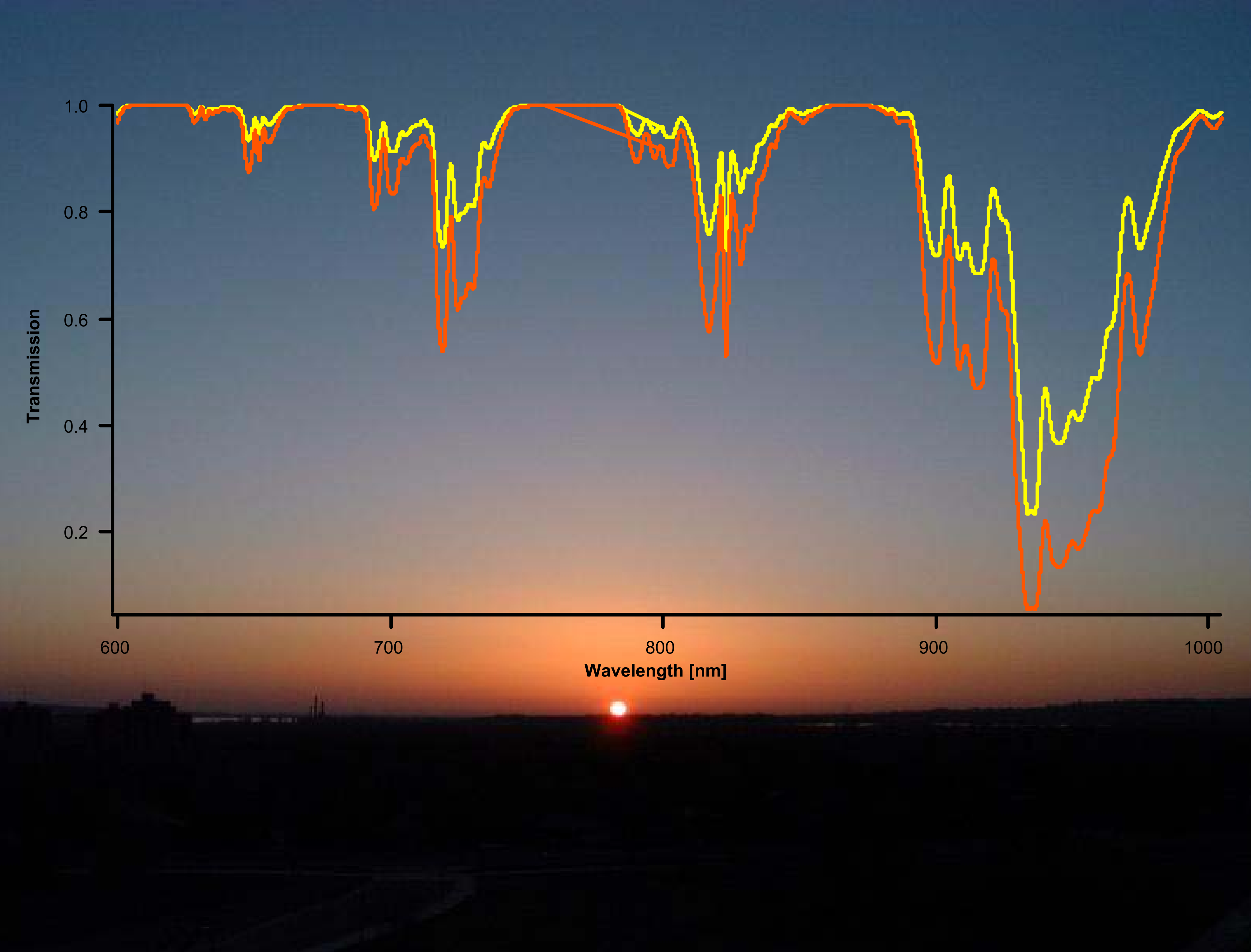
Goals of this study

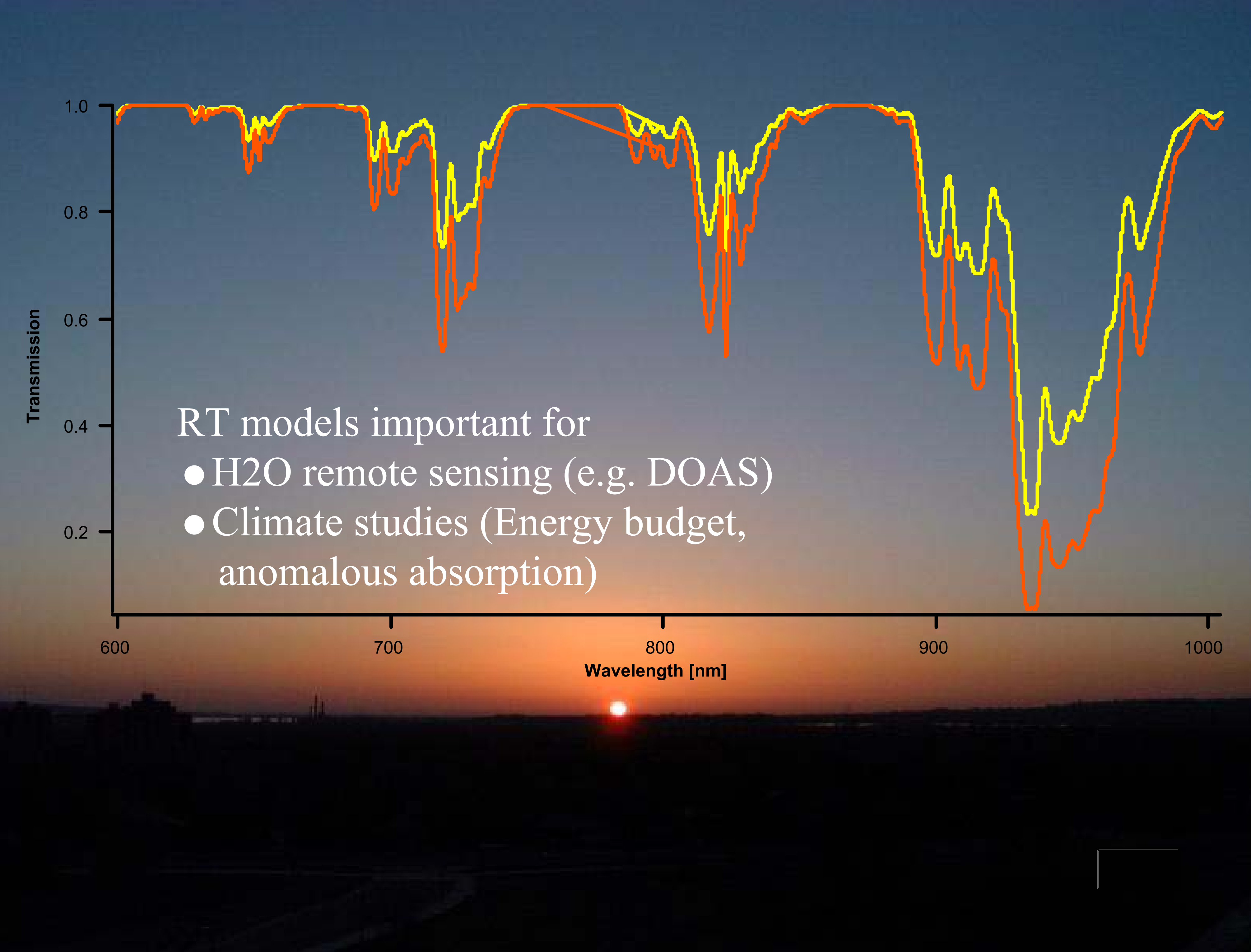
- **Comparison of GPS meteorology with the DOAS technique**
  - Comparison of time series of PW
  - Verification of slant water vapor retrievals from GPS
- **Study of H_2O-absorption bands for radiative transfer**
  - How do retrievals from different bands compare ?
  - How consistent are the line strengths in different bands ?
- **Water vapor continuum absorption**
  - Field measurements of continuum absorption in the visible spectral region

Problems of radiative transfer in the visible and NIR

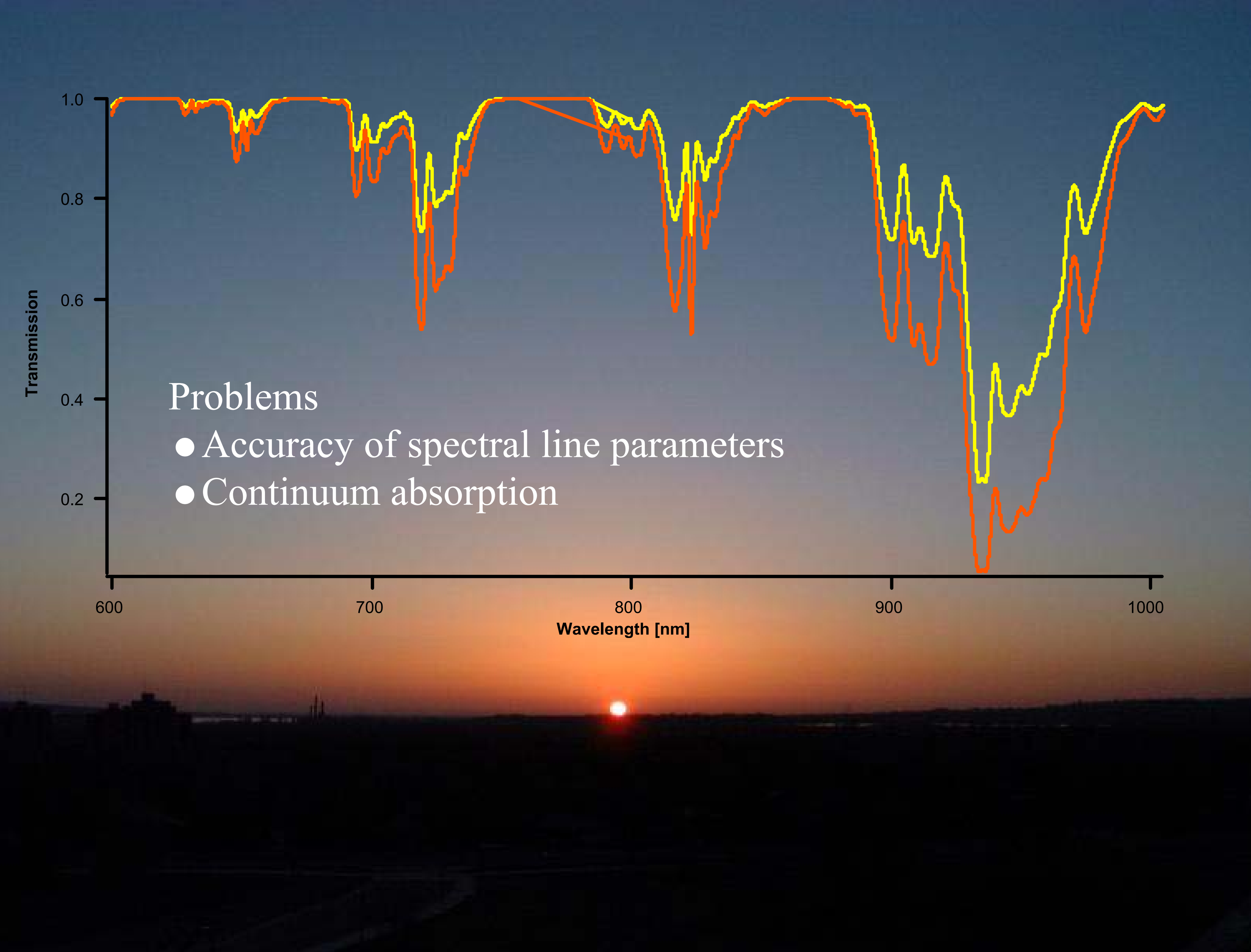
- **Spectral line parameters**
  - absolute accuracy
  - consistency between different H_2O-bands
  - both important for remote sensing techniques, e.g. Differential Optical Absorption Spectroscopy (DOAS)
- **Water vapor continuum**
  - additional broadband absorption introduced to match RT model with observations
  - physical origin: line shapes or water dimer ?
  - anomalous absorption in clear skies ?

Transmission
1.0
0.8
0.6
0.4
0.2
600
700
800
900
1000
Wavelength [nm]

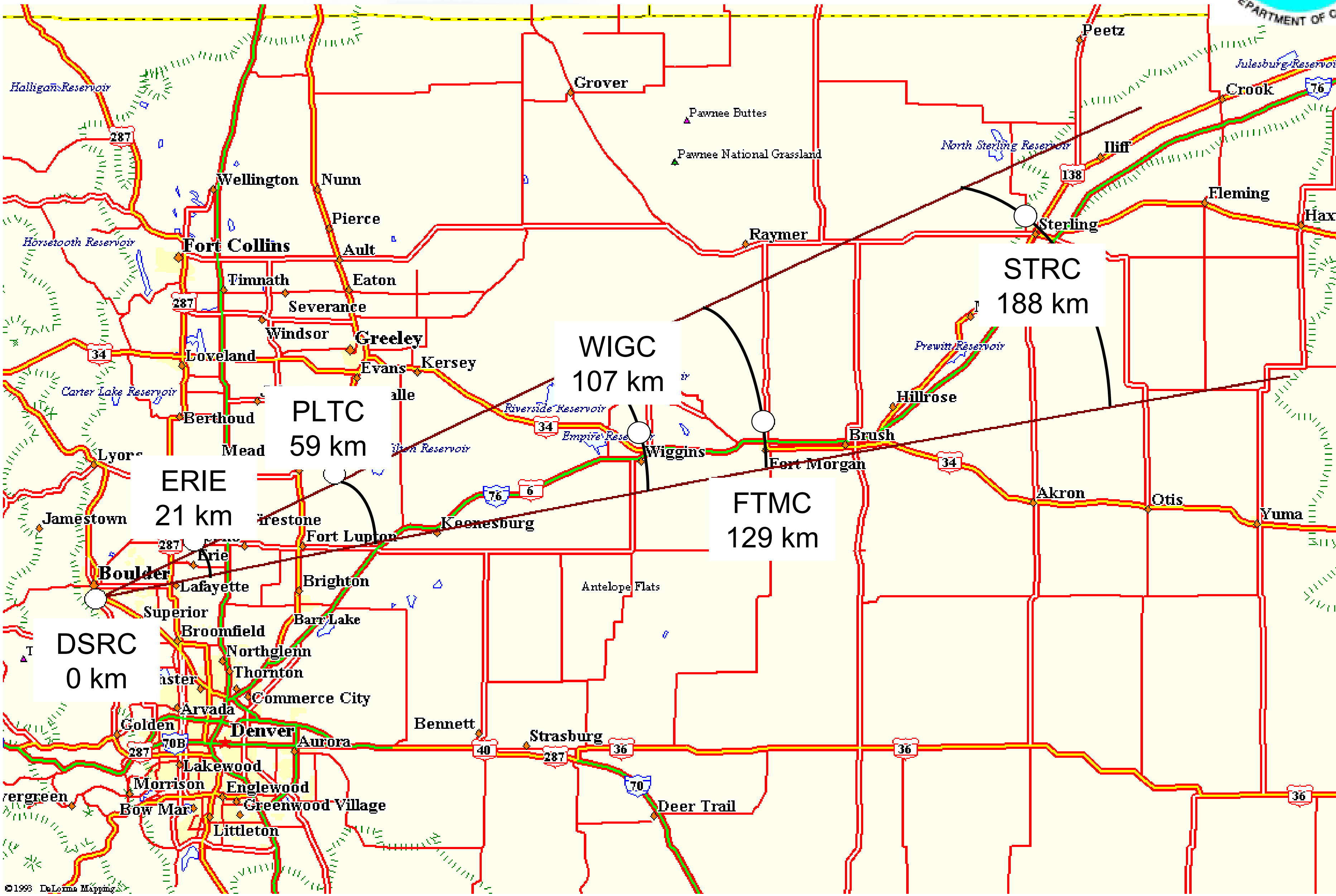

1.0
0.8
0.6
0.4
0.2
Transmission
600
700
800
900
1000
Wavelength [nm]



RT models important for
● H2O remote sensing (e.g. DOAS)
● Climate studies (Energy budget, anomalous absorption)
Transmission
1.0
0.8
0.6
0.4
0.2
600
700
800
900
1000
Wavelength [nm]


1.0
0.8
0.6
0.4
0.2
Transmission
600
700
800
900
1000
Wavelength [nm]
Problems
● Accuracy of spectral line parameters
● Continuum absorption

GPS network

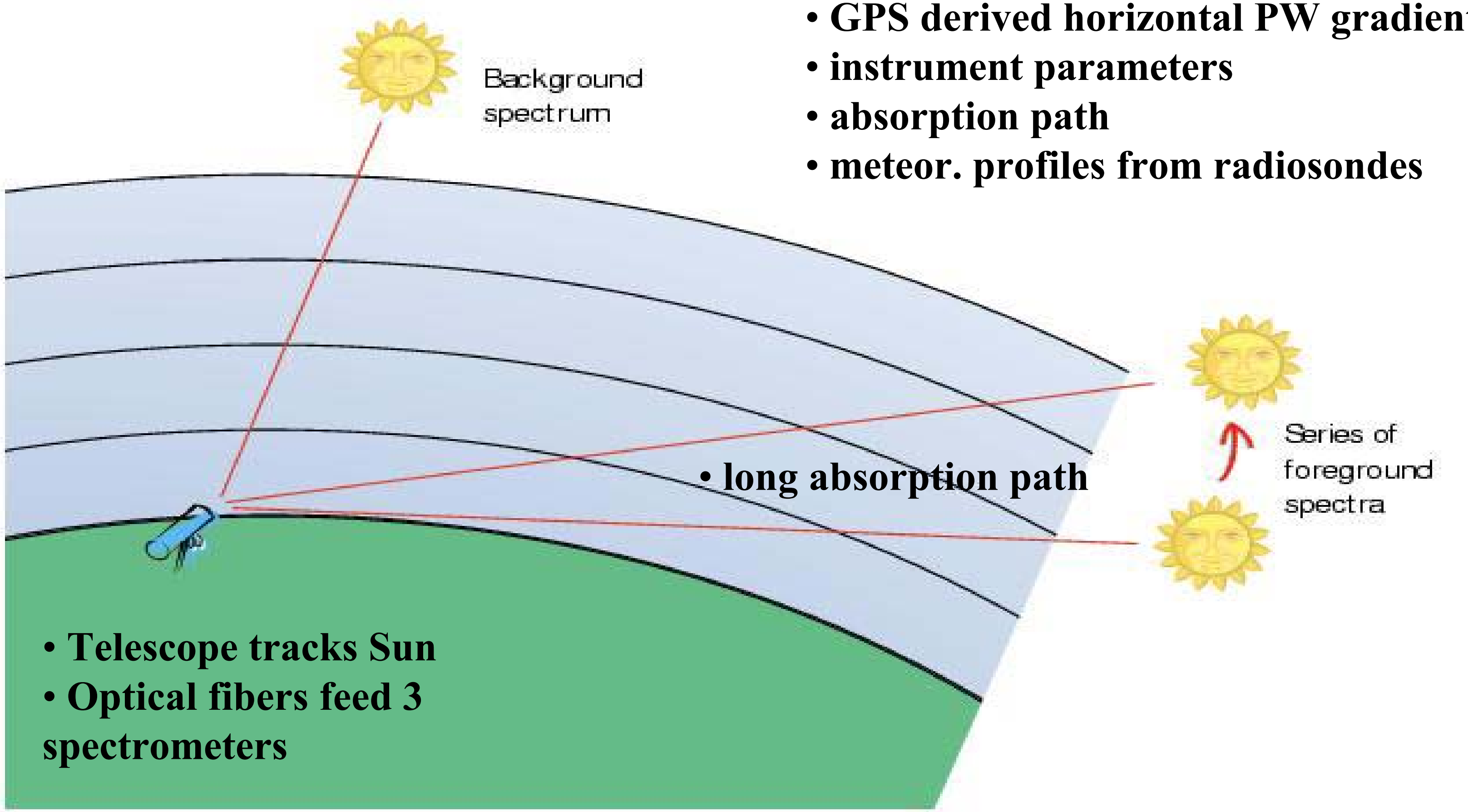


DSRC
0 km
ERIE
21 km
PLTC
59 km
WIGC
107 km
FTMC
129 km
STRC
188 km
Boulder
Fort Collins
Greeley
Denver
Sterling
Fort Morgan
Wiggins
Brush
Akron
Yuma
©1993 DeLorme Mapping

DOAS

Observation of differential spectra referenced to a high-Sun background

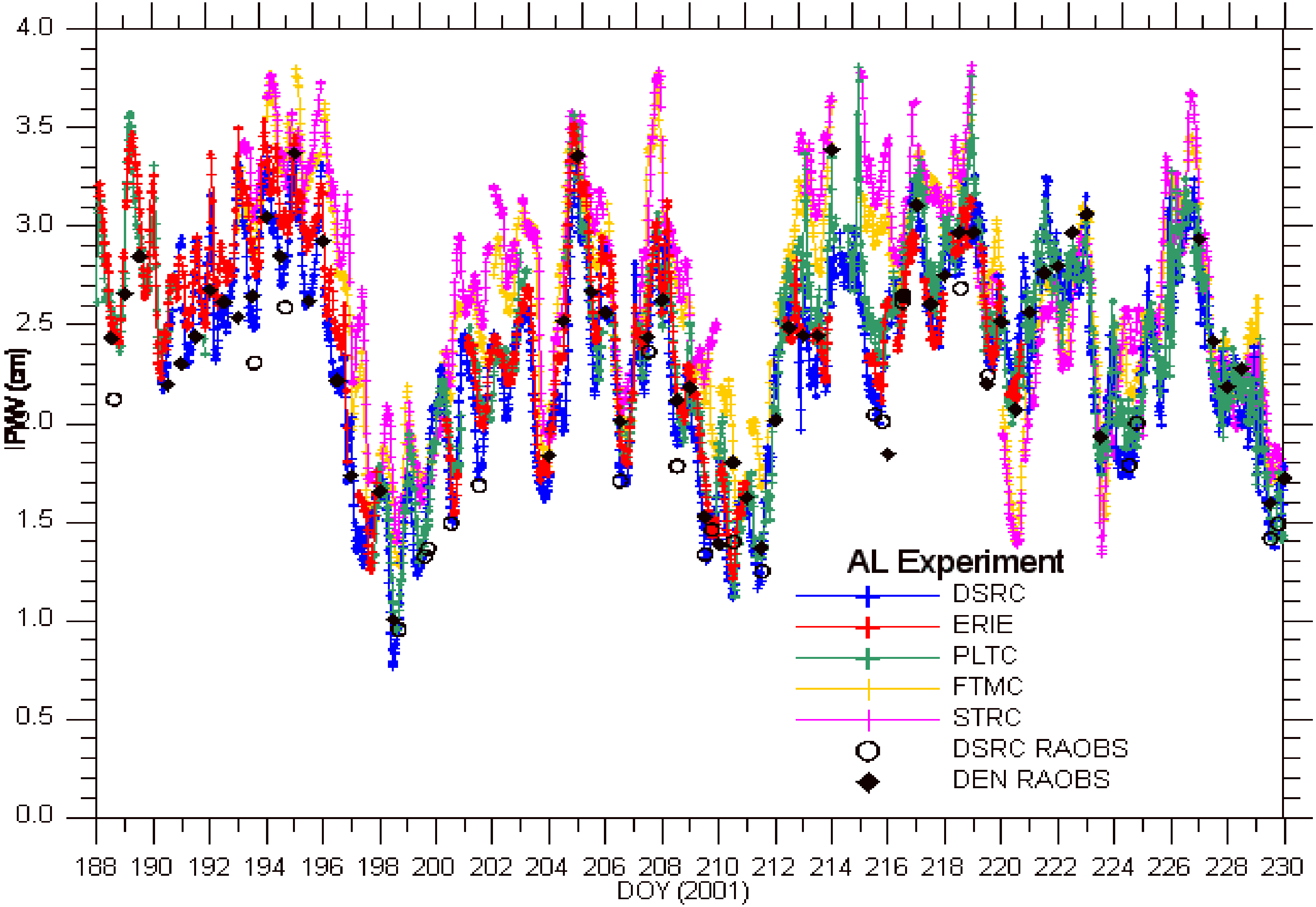
Separation of continuum and line absorption using RTM including
- **GPS derived horizontal PW gradients**
- **instrument parameters**
- **absorption path**
- **meteor. profiles from radiosondes**



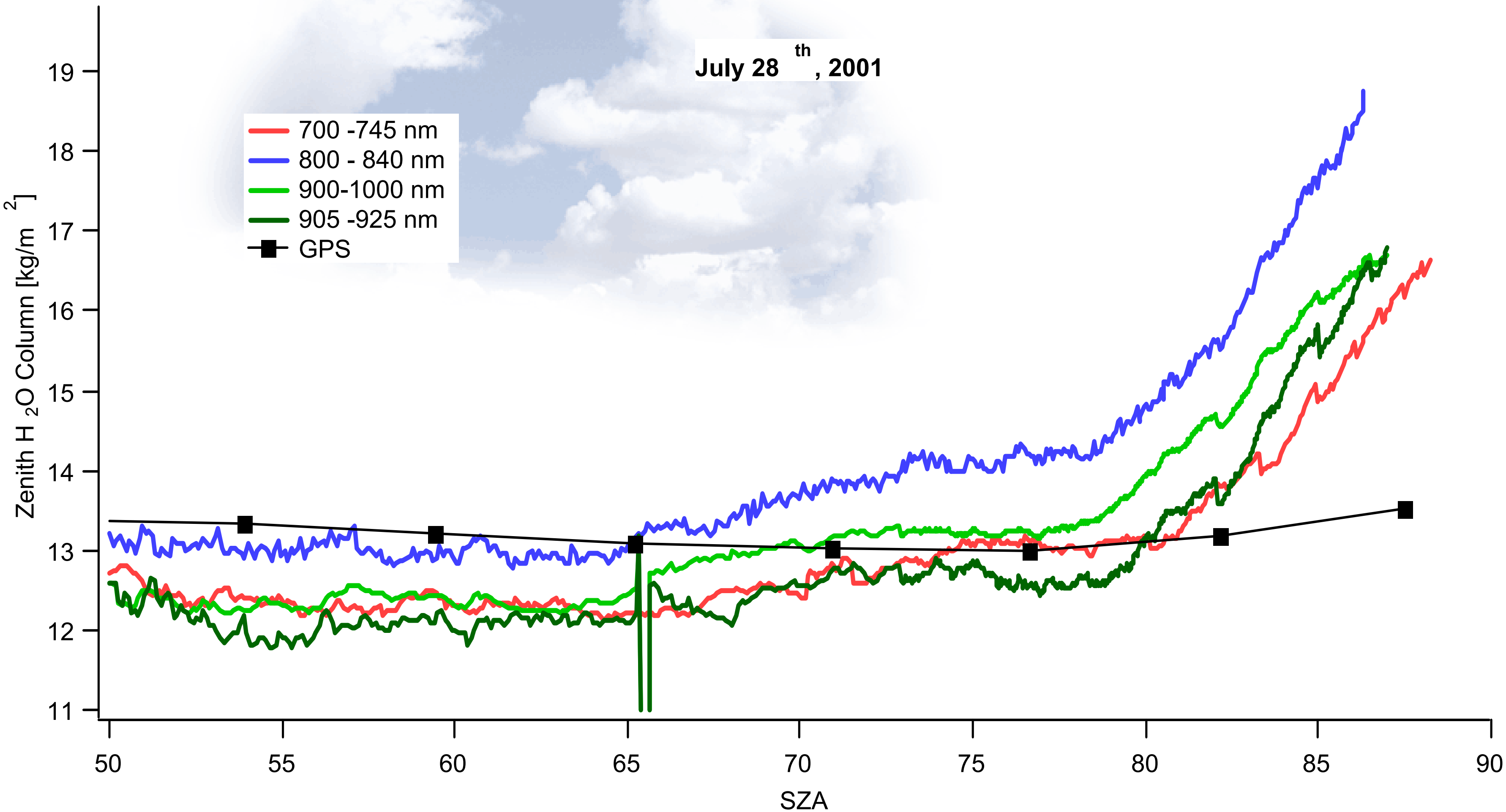
Approach

- **Using GPS meteorology in a DOAS field experiment**
  - Measure solar absorption spectra during sunrise
  - Chain of GPS receivers to constrain the water vapor amount along the absorption path (horizontal gradients)
  - Compare model spectra based on GPS retrievals with measured solar spectra
  - Compare PW retrievals from different H_2O absorption bands with GPS time series
- **Using DOAS to test slant PW retrievals from GPS**
  - DOAS provides highly accurate measurements of slant PW column towards the Sun
  - Compare these with GPS slant PW estimates in direction of satellites close to the Sun

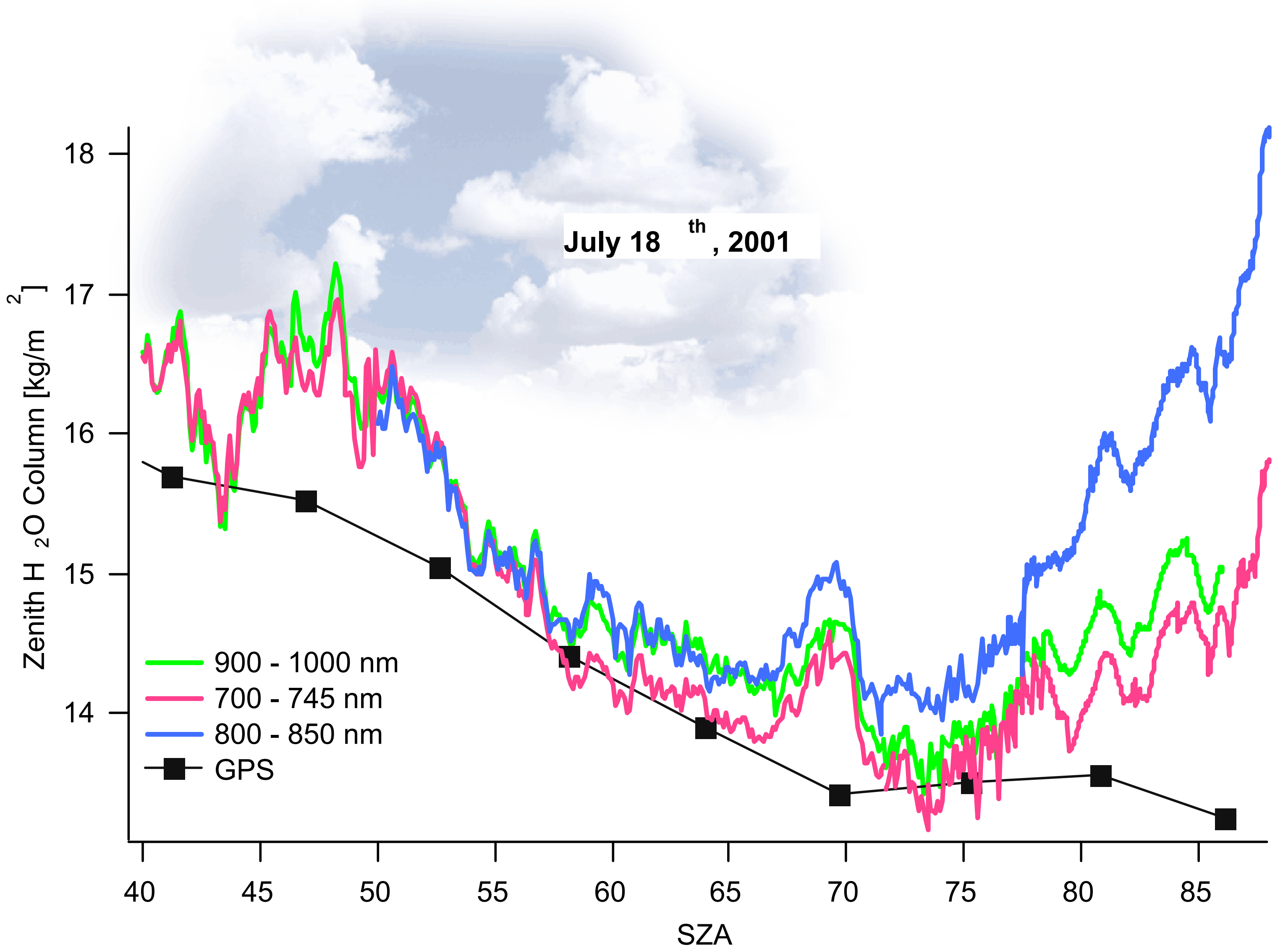
PW time series



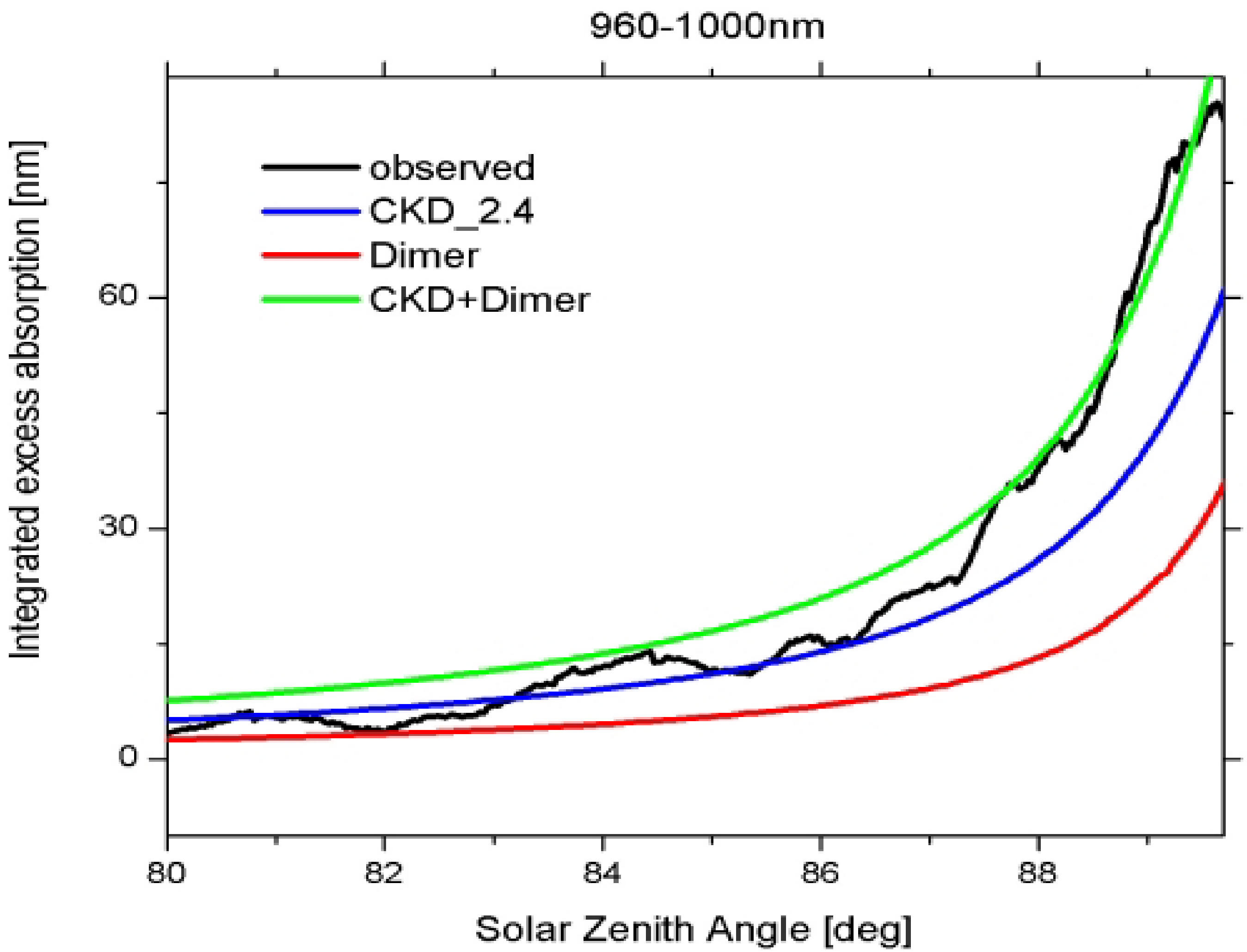
PW time series



PW time series



Excess absorption

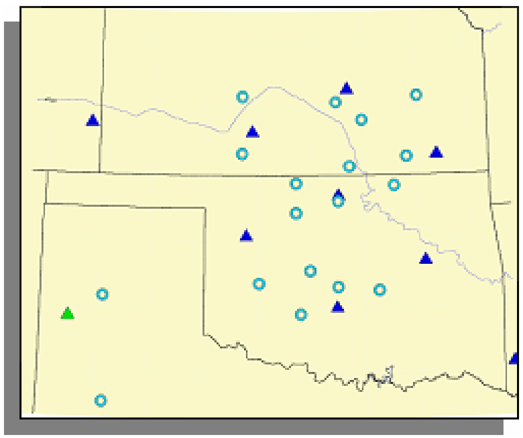


Preliminary results

- **Good agreement between DOAS and GPS**
  - Average bias < 0.5 mm PW
  - Biases between different H_2O-bands from 0.1 to 1 mm PW
- **H_2O-absorption bands**
  - Band averaged line strengths agree < 10 % (in strong bands)
  - Identified biases can be used to correct RT models
- **Quantification of water vapor continuum absorption**
  - CKD-model overestimates continuum in 940 nm band
  - Both line shape contributions and water dimers are present
- **GPS meteorology is a reliable tool to constrain water vapor amounts for radiative transfer studies**

Other Projects

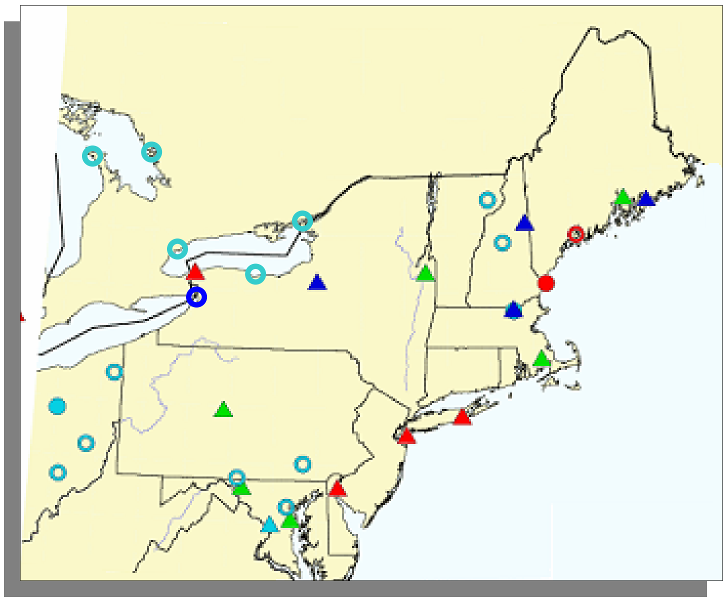
- International H_2O Project (IHOP) 2002.
  - The branch will acquire and process all available GPS and collocated surface met observations made in the region during the campaign (5/13/02 – 6/25/02);
  - GPS-IPW retrievals from NPN sites will be distributed to forecasters, modelers and researchers in real-time. Data from other sites (including SuomiNet sites) will be processed and distributed as soon as they are available;
  - GPS and surface met observations will be archived for reprocessing and further study.



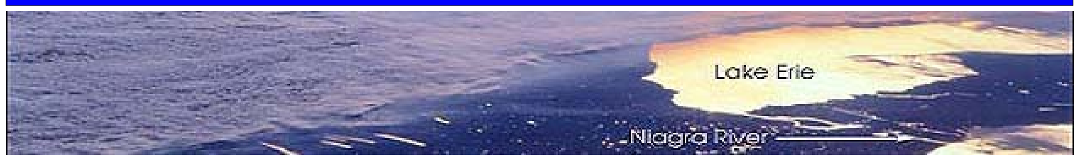
International H_2O Project
IHOP_2002

Other Projects

- New England Forecasting Pilot Program.
  - The branch will acquire and process all available GPS and collocated surface met observations made in the region during the experiment;
  - GPS-IPW retrievals from NPN sites will be distributed to forecasters, modelers and researchers in real-time.
  - GPS and surface met observations will be archived for reprocessing and further study.

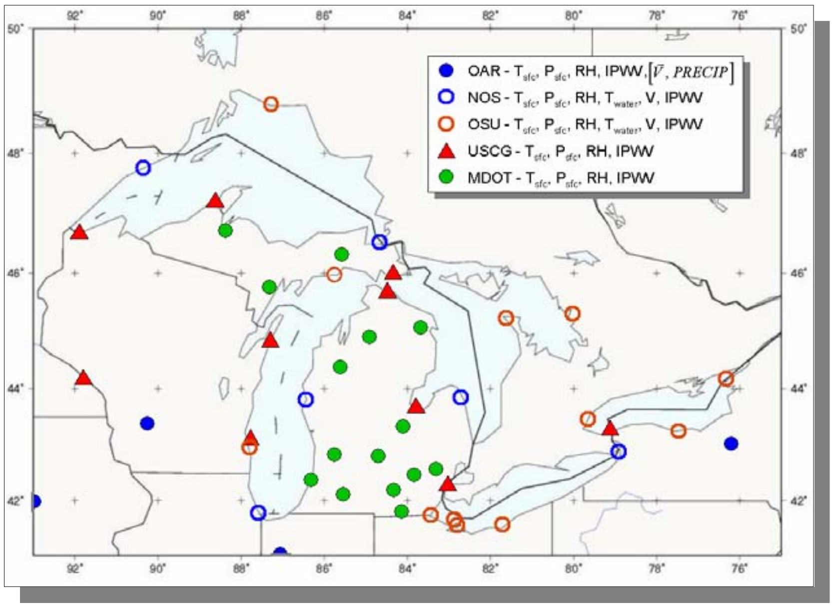


The NOAA New England Forecasting Pilot Program: High-Resolution Temperature and Air Quality



Other Projects

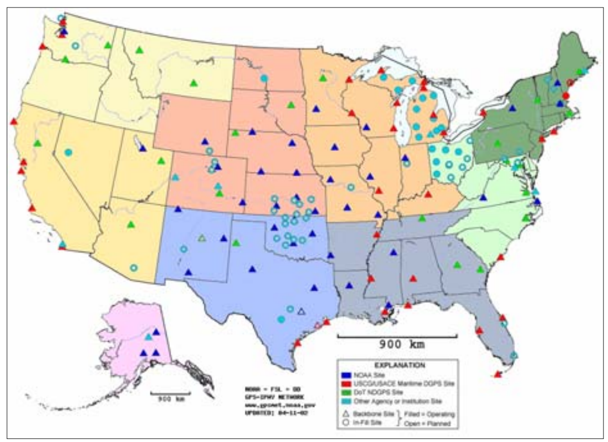
- NOAA/NOS Great Lakes Partnership Program.
  - The NOAA National Ocean Service (NOS) Partnership Program is funding a project to improve the accuracy of the International Great Lakes Datum by installing GPS receivers and Sfc. Met sensors at selected water level sites along the Great Lakes.
  - The GPS and Sfc. met data acquired at these sites will also be used to monitor the IPW in the atmosphere for weather forecasting applications.



- This is a cooperative effort between FSL, other NOAA Research organizations, the National Weather Service, the Ohio State University, Environment Canada, the U.S. Coast Guard, and the Michigan Department of Transportation.

Other Projects

- Atmospheric Infrared Sounder Calibration/Validation.
  - AIRS simultaneously measures in more than 2,300 spectral channels in the range of 0.4 to 1.7 µm and 3.4 to 15.4 µm.
  - Seth Gutman (FSL) and James Yoe (NESDIS Office of Research and Applications) are co-principal investigators.
  - Comparisons between GPS IPW and AIRS, GOES, MODIS and POES TPW retrievals will be made on each Aqua (EOS-PM) overpass of the GPS-Met Demonstration Network and other international sites.



NOAA Forecast Systems Laboratory
2002 Technical Review

Future Directions

Seth Gutman
NOAA Forecast Systems Laboratory

May 14, 2002

A Look Toward the Future

It's May 14, 2010.

- The GPS Block IIF satellites are being replaced by the new Block III spacecraft.
- The EC Galileo constellation has been fully operational for about one year.
- There are 15-20 Global Navigation Satellites in view at all times over North America.
- The NOAA GPS-Met Demonstration Network transitioned from research to operations within the National Weather Service back in 2008.
- The Operational GPS-Met Network consists of about 400 backbone sites and 600 in-fill sites throughout North America.

GPS-Met in 2010

- The GPS-Met Network continues to grow as new GPS sites are brought on line for real-time POS/NAV applications.
- The network delivers absolute tropospheric delays, delay gradients and IPWV every 15 minutes. Relative delays and IPWV are calculated every epoch in areas of very dense coverage under special conditions (e.g. severe weather).
- Data from the IGS Global Tracking Network are used routinely for environmental satellite calibration and validation, seamlessly tying together the observations from hundreds of platforms and sensors in space.

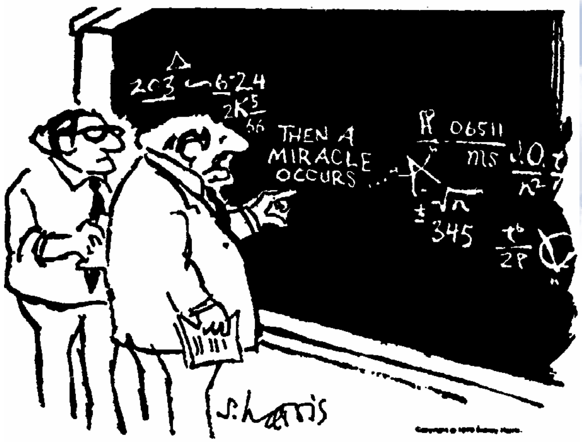
GPS-Met in 2010

- Differential correctors are provided by NGS for real-time high accuracy (~ 20 cm) GPS positioning and navigation.
- The correctors are calculated from data provided by NOAA operational space and tropospheric weather models that continuously assimilate data from all available environmental observing systems, including ground and space-based GPS receivers.
- This leads to private/commercial hands-off or robotic land, sea, and air transportation systems.
- For National Defense, re-locatable windows can be quickly established anywhere on the planet that produce *very high accuracy* correctors for unmanned or tele-operated military operations.

Forecast Systems Laboratory
Boulder, Colorado

How Do We Get There?

- Vision: the GPS-Met Demonstration Network transitions to operations in 2008.



"I think you should be more explicit here in step two."

  - GPS-IPW is ready to be considered for transition to operations, but...
  - What are the roles and responsibilities of NOAA Research and NWS in observing system technology transfer?
  - What can we do to facilitate the process?

- Vision: the Operational GPS-Met Network consists of about 400 backbone sites and 600 in-fill sites throughout North America.
  - A lot depends on how NWS wants to implement GPS-Met; they have a few options.
  - We expect that the demonstration network will form the backbone of an operational GPS-Met system.

How Do We Get There?

- We expect that GPS receivers at NWS Upper Air and lightning monitoring sites will be capable of calculating tropospheric delays as well as providing differential corrections for sondes, and time transfer for lightning detection and location.

- Vision: the GPS-Met Network continues to grow as new GPS sites are brought on line for real-time POS/NAV applications.
  - Local government agencies will augment state government GPS coverage for 911 and ITS activities. This will bring the average distance between GPS receivers in the U.S. to about 50 km.
  - Local Area Augmentation Systems used for terminal aircraft navigation throughout North America will be capable of GPS-Met calculations and be part of the network.

How Do We Get There?

- Vision: the network delivers absolute tropospheric delays, delay gradients and IPWV every 15 minutes. Relative delays and IPWV are calculated every epoch in areas of very dense coverage under special conditions (e.g. severe weather).
  - We think we know how to do this right now.
- Vision: data from the IGS Global Tracking Network are used routinely for environmental satellite calibration and validation, seamlessly tying together the observations from hundreds of platforms and sensors in space.
  - Inter-calibration of satellite sensors and continuous validation of physical retrievals are needed to reduce ambiguity in global climate observations.

How Do We Get There?

- GPS may provide part of the solution because:
  - GPS refractivity measurements are based on time standards that are improving (as opposed to degrading) with time and;
  - GPS measurements require no external calibration.
- We recommend that this concept be evaluated by the Joint NASA/NOAA/NSF Center for Satellite Data Assimilation.

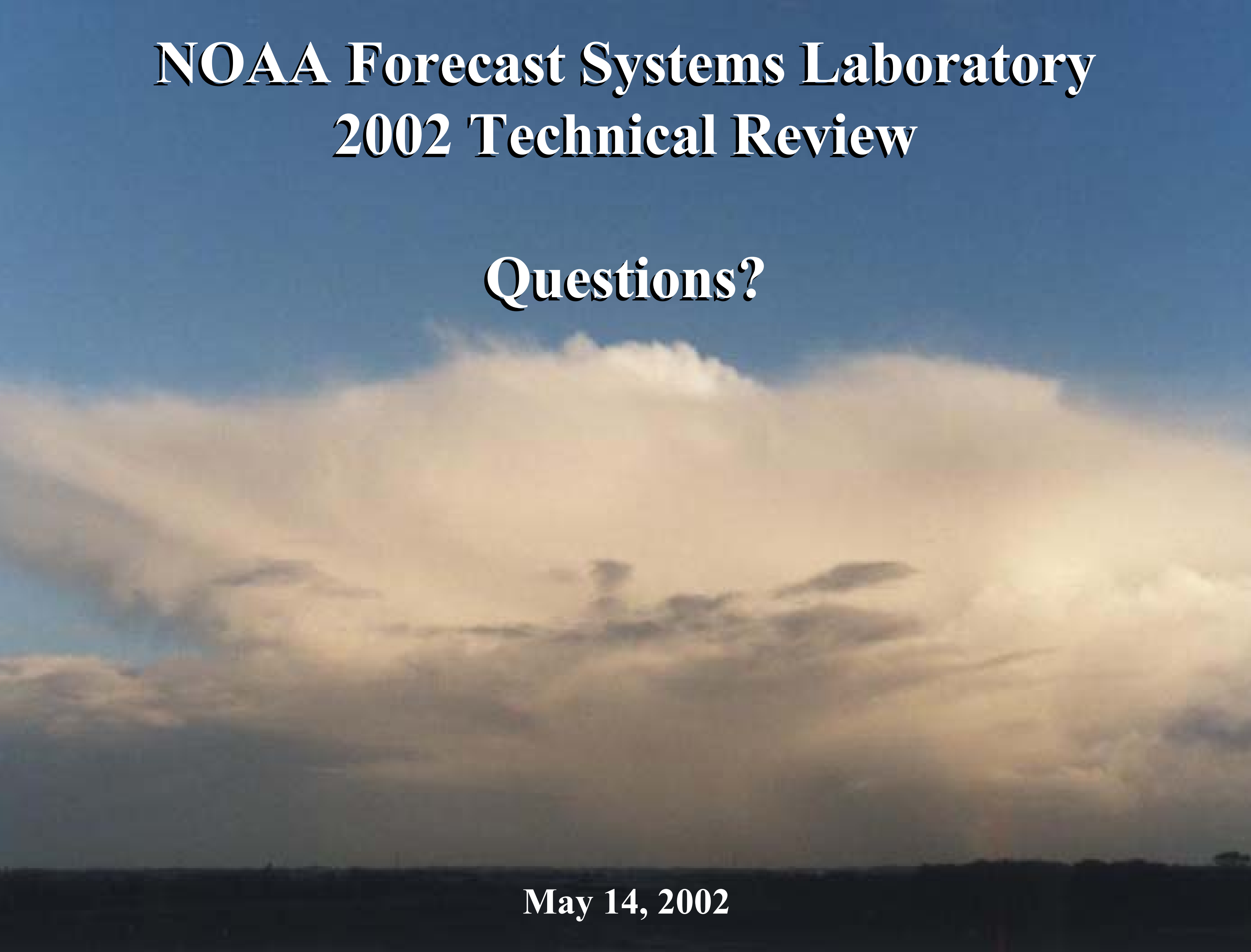
- Vision: Differential GPS correctors for high accuracy positioning are calculated from data provided by NOAA operational space and tropospheric weather models.
  - FSL, SEC and NGS have been awarded a grant from the ***Interagency GPS Executive Board (IGEB)*** to study the use of space and tropospheric weather models for high accuracy GPS POS/NAV applications.

How Do We Get There?

- The IGEB is staffed by representatives from various agencies, including the Departments of Commerce, Interior, Defense, and Transportation.
- Atmospheric-induced signal delays that cannot be corrected for analytically are currently the ***greatest impediment to high accuracy (< 20 cm) differential GPS positioning accuracy over long (> 10 km) baselines***.
- NOAA has an opportunity to develop models that provide real-time atmospheric correctors and QC flags for N/DGPS and the GPS modernization.
- We envision this as an ***operational nowcaster*** running at NCEP, with error descriptors (a.k.a.messages) broadcast by N/DGPS sites, GPS augmentation systems, and perhaps even the GPS Block III satellites themselves.

New Capabilities

- Hands-off or robotic land, sea, and air transportation systems:
  - Smart cars that drive on ‘autopilot’;
  - Private aircraft that navigate themselves;
  - Pinpoint search & rescue.
- For National Defense applications, re-locatable windows can be quickly established anywhere on the planet that produce *very high accuracy* correctors for unmanned or tele-operated military operations, e.g. mine clearance and ordinance disposal.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Questions?
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